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# AN EXTENSION OF FROST'S MIXTURE RULE TO INCLUDE THE EFFECTS OF MULTIPLE IONIZATION ON ELECTRICAL CONDUCTIVITY

## Application to Equilibrium Air at 3,000° to 28,000° K

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16. Abstract

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NOMENCLATURE

This is a partial alphabetical listing of the present nomenclature. All symbols are defined locally in the text where they are first used.

| | |
|---|---|
| $\tilde{A},\tilde{B},\tilde{C},\tilde{D}$ | constants used in equation (10) |
| $e$ | absolute value of electron charge |
| $f^o$ | isotropic part of electron distribution function |
| $k$ | Boltzmann's constant |
| $m_e$ | electron mass |
| $N$ | order of approximation (eq. (9)) |
| $n_e, n_i, n_n$ | number densities: electrons, ions, neutral particles |
| $T$ | gas temperature |
| $T_e$ | electron temperature |
| $v$ | electron speed |
| $Z$ | mean ionic charge of gas (eq. (4)) |
| $Z_i$ | ionic charge of species $i$ |
| $\beta, \beta_e$ | parameters defined by $\frac{m_e}{2kT}$ and $\frac{m_e}{2kT_e}$, respectively |
| $\Gamma_{ee}$ | parameter defined by, $\frac{4\pi e^4}{m_e^2} \ln \bar{\Lambda}$ |
| $\Gamma_{eI}$ | coulombic collision parameter defined by equation (6) |
| $\Gamma_{ei}$ | parameter defined by equation (7) |
| $\gamma_E$ | factor that accounts for effects of electron-electron collisions in equation (4) |
| $\gamma_{UZ}(N)$ | small $\ln \bar{\Lambda}$ correction factor for $\sigma_{SH}$ |
| $\bar{\Lambda}$ | ratio of Debye length to the average impact parameter for a 90° Coulomb deflection |
| $\lambda_D$ | Debye length |
| $\nu_{CF}$ | effective coulomb collision frequency used in $\sigma_F$ expression |

| | |
|---|---|
| $\nu_{ei}$ | Coulomb collision frequency between electrons and species i |
| $\nu_{ei_F}$ | effective collision frequency between electrons and species i (eq. (11)) |
| $\nu_N$ | collision frequency for momentum transfer between electrons and neutrals (eq. (2)) |
| $\nu_t$ | total effective collision frequency for electrons, $\nu_N + \nu_{CF}$ |
| $\sigma$ | electrical conductivity defined by equation (1) |
| $\sigma_{en}$ | collision cross section for momentum transfer between neutral species *n* and electrons |
| $\sigma_F$ | electrical conductivity defined by equation (1) with $\nu_N$ replaced by $\nu_t$ |
| $\sigma_{SH}, \sigma_{SHU}$ | electrical conductivity of fully ionized gas defined by equations (4), (5), and (9) |

Subscripts

| | |
|---|---|
| e | electron |
| i | ion |
| n | species *n* neutral |

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## SUMMARY

An extension of previously developed expressions for the electrical conductivity of a plasma is presented. This extension includes an accurate accounting for the effects of ionic charge in the coulombic collision frequency and a correction factor that extends the range of applicability of the equation for the conductivity of a fully ionized gas. The resulting expression is applicable over a large range of temperatures and pressures. It is applied to the problem of obtaining accurate values for the electrical conductivity of equilibrium air. The temperatures and density ratios (based on standard atmospheric density) considered in this study range from 3,000° K to 28,000° K and $10^{-6}$ to $10^{2}$. The results, presented primarily in tabular form, include other useful plasma dynamic parameters for equilibrium air. Comparisons are also made with various other methods of calculating the electrical conductivity of air.

## INTRODUCTION

It was recently demonstrated (ref. 1), by an extensive treatment, that the electrical conductivity for partially ionized gases could be obtained accurately from an empirical mixture rule developed by Frost (ref. 2). The rule is a combination of "exact" solutions for the electrical conductivity of weakly and fully ionized plasmas. It is limited to gases composed of electrons, neutrals, and singly ionized particles, and hence is applicable only over temperature and pressure ranges in which the effects of multiply ionized species are negligible. In this report an expression of the Frost type is developed that would also account for the presence of multiply ionized ions in high temperature gases. The analysis is presented in a form applicable to two temperature plasmas as well as to plasmas in thermal equilibrium. The resulting expression is then used to determine the electrical conductivity of equilibrium air to 28,000° K for density ratios from $10^{-6}$ to $10^{2}$, based on standard atmospheric density. These results are compared with results obtained using a modified Chapman-Enskog first approximation (refs. 3, 4).

## DEVELOPMENT OF MIXTURE RULE

The Frost mixture rule for the electrical conductivity of a partially ionized gas is outlined briefly, extended to apply to gases containing multiply ionized particles, and modified to include corrections for small values of the logarithmic term in the electrical conductivity of a fully ionized plasma.

The electrical conductivity for a weakly ionized gas can be written (refs. 5, 6)

$$\sigma = \frac{4\pi e^2}{3m_e} \int_0^\infty f^o \frac{d}{dv}\left(\frac{v^3}{\nu_N}\right) dv \tag{1}$$

Here $e$ is the electron charge, $m_e$ is the electron mass, $v$ is the electron speed, and $f^o$ is the isotropic part of the electron velocity distribution function. The form of this distribution function will depend on the magnitude of the electric field strength influencing the charged particles (ref. 6). In equation (1), $\nu_N$ is the total collision frequency for momentum transfer between electrons and neutral species. In expanded form it is written

$$\nu_N = v \sum_n n_n \sigma_{en}(v) \tag{2}$$

where $n_n$ is the number density of type "-n" neutral species and $\sigma_{en}$ is the total collision cross section for momentum transfer between neutral species -n and electrons. The summation in equation (2) is over all neutral species.

Frost (ref. 2) modified the collision frequency in equation (1) to include coulombic collisions in an empirical fashion such that the resulting expression yielded the correct conductivity in the completely ionized limit (ref. 7), agreed with equation (1) in the weakly ionized limit, and was consistent with Hwa's results in regions between these two limits (ref. 8). In particular, Frost replaced $\nu_N$ by $\nu_t$ defined as

$$\nu_t = \nu_N + \nu_{CF} \tag{3}$$

where $\nu_{CF}$ is an empirically determined coulombic collision frequency that causes equation (1) to agree with the Spitzer-Härm (ref. 7) result for a fully ionized gas when the mean ionic charge equals unity. It has been demonstrated recently (ref. 1) that the Frost conductivity expression $\sigma_F$ yields results that accurately represent the electrical conductivity over the entire degree of ionization spectrum. A general form for $\nu_{CF}$ is developed in this report which allows $\sigma_F$ (eq. (1) with $\nu_t$ in place of $\nu_N$) to agree with the fully ionized result for a range of mean ionic charge. It was anticipated that this form would yield an accurate conductivity expression for gas mixtures composed of electrons, neutrals, and multiply ionized ions.

The Spitzer-Härm expression for the electrical conductivity of a fully ionized gas can be written (ref. 7)

$$\sigma_{SH} = \frac{8}{\sqrt{\pi}} \frac{\gamma_E}{\beta^{3/2}} \frac{e^2}{m_e Z \Gamma_{ee}} \tag{4}$$

where $\Gamma_{ee} \equiv (4\pi e^4/m_e^2) \ln \bar{\Lambda}$ is a parameter related to the electron-electron collision frequency (ref. 6), $\beta \equiv m_e/2kT$ is a parameter associated with the gas temperature, and $Z \equiv (1/n_e)\sum_i n_i Z_i^2$ is an expression for the mean ionic charge of the gas.[1] In these expressions $T$ is the gas temperature; $n_i$ and $Z_i e$ are the number density and charge of the species "i" ion, respectively; $\bar{\Lambda} \equiv (3kT/e^2)(kT/4\pi n_e e^2)^{1/2}$ is the ratio of the Debye length $[\lambda_D \equiv (kT/4\pi n_e e^2)^{1/2}]$ to the mean impact parameter for a 90° deflection between an electron and a singly charged ion;[2] and $\gamma_E = \gamma_E(Z)$ accounts for the effect of electron-electron collisions, and hence relates the Spitzer-Härm conductivity expression to that for a Lorentz gas. Equation (4) is considered to be an exact expression because it is based on a numerical solution rather than the usual truncated series solution of the Boltzmann equation. In its present form, however, it is applicable only to gases under the influence of very weak electric fields and hence the gases are in thermal equipartition.

For the more general case of nonequipartition of thermal energy (electron temperature, $T_e$, different from ion or gas temperature), resulting say, from the presence of a relatively strong electric field, equation (4) remains valid provided $T$ is replaced by $T_e$ (ref. 6).

In obtaining equation (4), Spitzer and Härm set the charge associated with the 90° impact parameter equal to unity in the logarithm. If the charge dependence of this impact parameter is left in the logarithmic term and nonequipartition effects are included in the analysis, one obtains[3]

$$\sigma_{SH} = \frac{8}{\sqrt{\pi}} \frac{\gamma_E}{\beta_e^{3/2}} \frac{e^2}{m_e \Gamma_{eI}} \tag{5}$$

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[1]Contrary to the suggestion of reference 7 to sum over only positive ions in determining $Z$, it appears that the sum can be taken over all ions regardless of the sign of the charge. Thus one obtains a contribution to the conductivity from the coulombic interaction between electrons and the negatively charged ions.

[2]The term $\bar{\Lambda}$ is also a measure of the ratio of the number of electrons in a Debye cube to the mean ionic charge of the plasma and is inversely related to the effective minimum scattering angle for a coulombic encounter.

[3]The analysis and results of reference 7 will apply for this case with $Z$ and $T$ (of ref. 7) replaced by $\Gamma_{eI}/\Gamma_{ee}$ and $T_e$, respectively. Thus, in equation (5) $\gamma_E = \gamma_E(\Gamma_{eI}/\Gamma_{ee})$.

where

$$\Gamma_{eI} = Z\Gamma_{ee} - \frac{4\pi e^4}{m_e^2}\sum_i \frac{n_i Z_i^2}{n_e}\, ln|Z_i| = \frac{1}{n_e}\sum n_i \Gamma_{ei}$$

$$\beta_e \equiv \frac{m_e}{2kT_e} \tag{6}$$

and where[4]

$$\Gamma_{ei} \equiv \frac{4\pi Z_i^2 e^4}{m_e^2}\, ln\left(\frac{\overline{\Lambda}}{|Z_i|}\right) \tag{7}$$

The term given by $\Gamma_{ei}$ is related to the coulombic collision frequency obtained by means of a Rutherford cross section by

$$\nu_{ei} = \frac{n_i}{v^3}\,\Gamma_{ei} \tag{8}$$

Thus we can also conclude that $\sum_i \nu_{ei} = n_e(\Gamma_{eI}/v^3)$. It should be noted that when all $|Z_i|$ equal unity, equations (4) and (5) are identical.

The results of Spitzer-Härm are valid to the order of $(ln\ \overline{\Lambda})^{-1}$ (ref. 1) because of the truncations involved in the coulombic collision integrals (ref. 7) and the use of a Debye cutoff in the evaluation of the coulombic cross sections. Similarly, equation (5) is of limited accuracy for $ln(\overline{\Lambda}/|Z_i|) \lesssim 10$.

In references 1 and 10 corrections for small values of $ln\ \overline{\Lambda}$ are developed for a fully ionized gas. The results are limited to values of

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[4]In a general nonequipartition situation where electrons and multiply charged ions exist the Debye length is given by

$$\lambda_D = \left[\frac{kT_e}{4\pi n_e e^2}\left(\frac{1}{1 + \frac{T_e}{n_e}\sum_i \frac{n_i Z_i^2}{T_i}}\right)\right]^{1/2}$$

Thus, one might expect to include this form for $\lambda_D$ in the evaluation of $\overline{\Lambda}$ in equation (7). However, as Delcroix (ref. 9) points out, in most instances involving collisions, the relative immobility of ions results in $\lambda_D = (kT_e/4\pi n_e e^2)^{1/2}$ being the proper form for the Debye length to use in equation (7). Thus, the form of $\Gamma_{ei}$ implied by equation (7) with $T_e$ in place of $T$ is applicable for nonequipartition studies of transport phenomena.

$Z_i = 1$ and have included ion shielding in the calculation of the Debye length. In the present paper the unified theory of Kihara and Aono (ref. 11) is utilized, via the equations given by Itikawa (ref. 12) and the matrix elements of Daybelge (ref. 10), to obtain a correction for small values of $\ln(\overline{\Lambda}/|Z_i|)$ which is valid for any ionic charge, $Z_i$. Also, the effects of ion shielding are neglected in the evaluation of the Debye length (see footnote 4). This correction when applied to equation (5) would yield

$$\sigma_{SHU}(N) = \gamma_{UZ}(N)\sigma_{SH} \tag{9}$$

where $\sigma_{SHU}(N)$ is the Nth approximation to the fully ionized conductivity based on the unified theory, and $\gamma_{UZ}(N)$ is the correction factor that enables $\sigma_{SH}$ to agree with the unified theory results when $\ln(\overline{\Lambda}/|Z_i|)$ is "small." (The unified theory is valid as long as $\overline{\Lambda}/|Z_i| >> 1$, whereas the Spitzer-Härm results require $\ln(\overline{\Lambda}/|Z_i|) >> 1$.)

The second approximation to the correction factor is

$$\gamma_{UZ}(2) = \frac{\left(\frac{3\pi}{32\gamma_E}\right)\Gamma_{eI}}{\Gamma_{eI} + \frac{4\pi e^4}{m_e^2} Z\tilde{A} - \frac{(9/4)\left[\Gamma_{eI} + (4\pi e^4/m_e^2)Z\tilde{B}\right]^2}{\sqrt{2}\left[\Gamma_{ee} + (4\pi e^4/m_e^2)\tilde{C}\right] + (13/4)\left[\Gamma_{eI} + (4\pi e^4/m_e^2)Z\tilde{D}\right]}} \tag{10}$$

where $\tilde{A} = -1.3670$, $\tilde{B} = -2.0337$, $\tilde{C} = -0.4478$, and $\tilde{D} = -1.9824$.[5] This approximation was used in the present calculations because it not only has a particularly simple form but in test calculations that included $Z_i = Z = 1$ and ion shielding, it agreed within 5 percent of the results of reference 1 for small $\ln \overline{\Lambda}$. In addition, at large $\ln \overline{\Lambda}$, $\sigma_{SHU}(2) = 0.978\ \sigma_{SH}$ when $Z_i = Z = 1$. This accuracy was considered sufficient for the present calculations. A first approximation to the small $\ln(\overline{\Lambda}/|Z_i|)$ correction given by

$$\gamma_{UZ}(1) = \frac{\left(\frac{3\pi}{32\gamma_E}\right)\Gamma_{eI}}{\left(\Gamma_{eI} + \frac{4\pi e^4}{m_e^2} Z\tilde{A}\right)}$$

yields poor results, especially at large $\ln(\overline{\Lambda}/|Z_i|)$.

The generalized form of the empirical coulombic collision frequency $\nu_{CF}$ is obtained by equating $\sigma_F$ for a fully ionized gas, where $f^o$ is Maxwellian

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[5]A similar small $\ln(\overline{\Lambda}/|Z_i|)$ correction factor based on the shielded coulomb potential (refs. 1, 10, 13) would yield an identical second-order correction except for the constant $\tilde{C}$ which would become -0.8670.

at $T_e$ (ref. 6), with $\sigma_{SHU}(2)$ from equation (9). To assure agreement with the earlier Frost result the same velocity and temperature dependence of reference 2 will be assumed here for $\nu_{CF}$; that is, for singly ionized ions

$$\nu_{CF} = 0.952 \frac{\sqrt{\beta_e}}{v^2} n_i \Gamma_{ei}$$

($n_i = n_e$ and $\Gamma_{ei} = \Gamma_{ee}$ for this case). Thus, for a plasma of multiply ionized ions one can take for this effective coulombic collision frequency

$$\nu_{CF} \equiv \sum_i \nu_{ei_F} = \frac{\sqrt{\beta_e}}{v^2} C_F \sum_i n_i \Gamma_{ei} = \sqrt{\beta_e}\, v C_F \sum_i \nu_{ei} = \frac{\sqrt{\beta_e}}{v^2} C_F n_e \Gamma_{eI} \tag{11}$$

The coefficient $C_F$, to be determined, enables $\sigma_F$ to equal $\sigma_{SHU}(2)$ for a fully ionized gas. Under these conditions

$$\left.\sigma_F\right)_{\substack{\text{fully}\\ \text{ionized}}} = \frac{5}{2C_F} \frac{1}{\beta_e^{3/2}} \frac{e^2}{m_e \Gamma_{eI}} \tag{12}$$

A comparison of equation (12) with (9) and (5) reveals the following expression for $C_F$

$$C_F = \frac{5\sqrt{\pi}}{16 \gamma_E \gamma_{UZ}} \tag{13}$$

Thus, if $\gamma_E = \gamma_E(\Gamma_{eI}/\Gamma_{ee})$ and $\gamma_{UZ}$ are known, $C_F = C_F(\Gamma_{eI}/\Gamma_{ee})$ can be determined.

Spitzer and Härm tabulated $\gamma_E(Z)$ for a wide range of $Z$. The largest root of the following quadratic expression accurately represents their tabular values over a range of $Z$ from 1 to 4.

$$\gamma_E^2 - 1.0610\, \gamma_E - 0.0207\, Z + 0.2995 = 0 \tag{14}$$

This expression also represents $\gamma_E = \gamma_E(\Gamma_{eI}/\Gamma_{ee})$ when $Z$ is replaced by $\Gamma_{eI}/\Gamma_{ee}$ in the analysis of reference 7. Thus, with this substitution, combining equations (14) and (13) yields the following results.

| $\Gamma_{eI}/\Gamma_{ee}$ | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $\gamma_{UZ} C_F$ | 0.952 | 0.811 | 0.748 | 0.706 |

For most plasmas of interest, it is a good approximation to take $Z_i = Z = 1$ and hence $\Gamma_{eI} = Z\Gamma_{ee}$. At very high temperatures, however, depending upon the relative number densities, the presence of multiply ionized ions may cause the second term in equation (6) to be significant.

It is also possible to have $|Z_i| = 1$ such that the second term in equation (6) vanishes while the mean ionic charge $Z$ is greater than unity. This situation will occur in a plasma in which a large percentage of negatively (singly) charged ions is present. In fact, it occurs for air at the higher pressures and lower temperatures illustrated below, indicating the importance of including negatively charged ions in the evaluation $Z$.

## RESULTS AND DISCUSSION

The foregoing development is general and the resulting conductivity expression for $\sigma_F$ is valid for any gas, even when subject to relatively strong electric fields (ref. 6). The results that follow, however, are based on calculations for equilibrium air only. This limitation implies that $T_e = T$ in the preceding equations and that the distribution function $f^o$ of equation (1) is Maxwellian.

In presenting the results, we first consider values of $\sigma_F$ for equilibrium air and compare them with conductivities obtained by other schemes. Next the effects of mean ionic charge variation and the small $ln(\overline{\Lambda}/|Z_i|)$ correction on the conductivity of a fully ionized gas are discussed. Then conductivity results based on various calculation schemes are given as functions of pressure and temperature. Finally miscellaneous topics are evaluated, such as how the use of the coulombic collision frequency ratio $(\Gamma_{eI}/\Gamma_{ee})$ rather than the mean ionic charge (Z) affects the evaluation of $\sigma_{SH}$; when the fully ionized conductivity expressions yield accurate results for partially ionized gases; and the contribution of negatively charged ions on the conductivity calculations.

### Evaluation of Mixture Rule

The expression for $\sigma_F$ ((1) with $\nu_t$ in place of $\nu_N$) was used to evaluate the electrical conductivity of equilibrium air for the temperature and standard atmospheric density ratio ranges of 3,000° to 28,000° K and $10^{-6}$ to $10^2$, respectively.

The results of the electrical conductivity calculations for air are presented in tables 1-9 and figures 1 and 2. The species considered in the air calculations were $N_2$, $N_2^+$, NO, $NO^+$, $O_2$, $O_2^+$, N, $N^+$, $N^{+2}$, $N^{+3}$, $O^-$, O, $O^+$, $O^{+2}$, $O^{+3}$, A, $A^+$, $A^{+2}$, $A^{+3}$, and e. Their equilibrium concentrations were obtained from references 14 and 15. The coulomb collision frequencies were determined as described above. The cross sections for electrons with $O_2$, NO, O, and N were obtained from references 16 through 19 and 4. At electron

energies below 0.16 eV, the e-$O_2$ cross section was assumed to be constant at the value corresponding to 0.16 eV. The cross sections for electrons with $N_2$ and A were obtained from references 20 and 21.

The electrical conductivity of equilibrium air, calculated according to the scheme outlined above, is presented in table 1. For comparison, the electrical conductivity of air based on the Chapman-Enskog first approximation modified to agree with $\sigma_{SH}$ (as given by eq. (4)) for the fully ionized case (refs. 3, 4) is given in table 2. So far results obtained by this latter method have been considered to be fairly accurate. The data from tables 1 and 2 are compared in figure 1 at two densities. As is apparent from this figure, a considerable difference can exist in the conductivity calculated by these two methods. It will be shown subsequently that the best agreement between the methods should occur when $ln\ \overline{\Lambda}$ is large, Z is about unity, and $\nu_{ei} >> \nu_N$. This is, of course, evident from the tables.

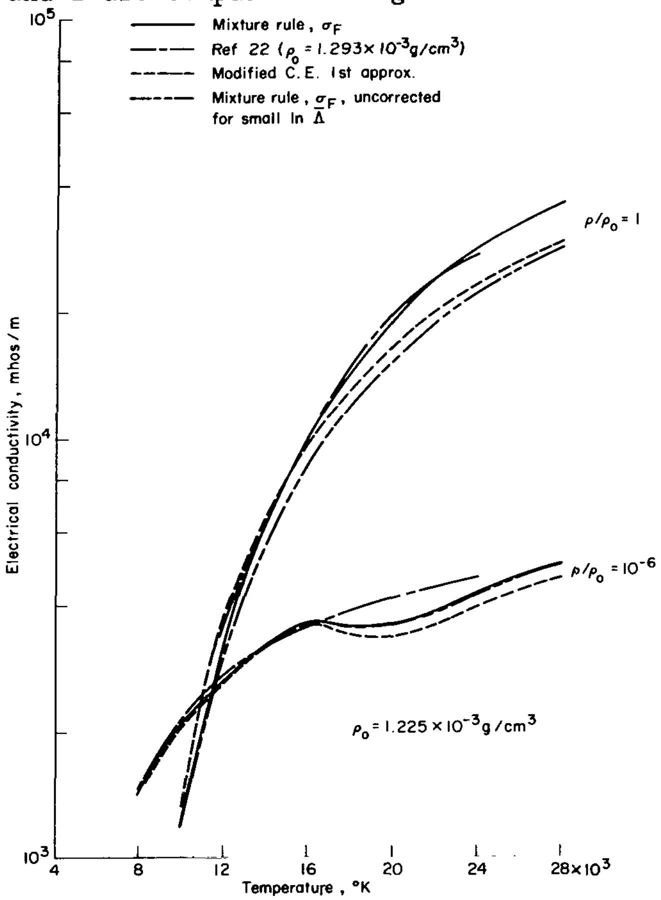

Figure 1.– Comparison of methods of calculating the electrical conductivity of equilibrium air at two densities.

All the previously mentioned species were included in the results presented in table 2. The collision integrals (ref. 4) or mean effective cross sections (ref. 3) needed to evaluate the conductivity based on the Chapman-Enskog first approximation were evaluated directly from the cross-section sources cited above. (This proved necessary because sample calculations indicated some discrepancies in the electron-atom collision integrals presented in ref. 4.)

As a further comparison, figure 1 also contains results from reference 22 in which the cross sections for electron-neutral particles were evaluated at the mean thermal energy of the electrons instead of being integrated over the electron collision frequency; and an additive rule that treated the ionized components of the electron resistivity as being distinguished by their degree of ionization was used to determine the resistivity of the air. The species number densities and their cross sections were taken from references other than those used herein. In view of these differences, which should affect numerical magnitudes, it is somewhat surprising that the results of reference 22 and those of the present work agree as well as shown. The agreement, however, should not be interpreted as a verification of the accuracy of the method used in reference 22. It is important to note that the temperature intervals used in the present calculations revealed

changes (discussed in the next section) in the temperature dependence of the electrical conductivity at lower densities that were masked by the rather large temperature intervals (6000° K) used in reference 22.

## Effect of Mean Ionic Charge Variation and Small $ln(\overline{\Lambda}/|Z_i|)$ Correction

In figure 1 the region where the electrical conductivity is insensitive to changes in temperature corresponds to a region where the effective electron collision cross section increases as a result of interaction with doubly ionized atoms. It is a region where the mean ionic charge increases rapidly with temperature. To the left of the region the gas is fully singly ionized while to the right the mean ionic charge is 2, indicating that the gas is effectively doubly ionized. Table 3 illustrates the variation of mean ionic charge for the range of temperatures and densities considered herein. These values of $Z$ were calculated from number densities obtained from the tabulations and plots of references 14 and 15. Hence, values of $Z$ less than 1 represent possible plotting and reading errors as well as numerical round-off errors. Such small discrepancies are thought to have a negligible effect on the results in view of other uncertainties (i.e., cross section data) in the analysis.[6] The electrical conductivity without the small $ln(\overline{\Lambda}/|Z_i|)$ correction term is also shown in figure 1. Table 4 indicates that small $ln\ \overline{\Lambda}$ corrections should be included in the conductivity results as they have been in table 1. In table 5 values of $\gamma_{UZ}$ are presented. As mentioned in the analysis the expression for $\gamma_{UZ}$ becomes invalid when $\overline{\Lambda}/|Z_i|$ is of order 1. Thus, at high temperatures and densities, when $ln\ \overline{\Lambda}$ is about unity the validity of the calculated values of $\gamma_{UZ}$ can be questioned. In fact, for these cases equation (10) yields very large - or even negative - values of $\gamma_{UZ}$. Hence, it was decided to set $\gamma_{UZ}$ equal to unity when the results of equation (10) were unrealistic (see table 5). For these cases, present theories are inadequate for determining the electrical conductivity, but the error in $\sigma_F$ should not be too severe because the degree of ionization is such that the electron-neutral encounters control the conductivity in these cases.

At low densities $ln\ \overline{\Lambda}$ is the order of 10 (table 4); hence, the correction factor $\gamma_{UZ}$ is nearly unity (table 5). Consequently, in figure 1 the correction to the mixture rule for small values of $ln(\overline{\Lambda}/|Z_i|)$ is negligible for $\rho/\rho_0$ of $10^{-6}$; whereas at the higher density ratio in this figure, the correction appears significant.

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[6]Special precautions, such as replotting the number densities and cross sections taken from the references and comparing them with the originals, were taken to locate and minimize the human errors that are bound to occur throughout the bookkeeping associated with this problem. On the basis of the number densities, cross sections, and the numerical procedure employed, the uncertainty of the present results is considered to be less than 2 percent.

## Comparison of Methods for Calculating Conductivity for a Range of Pressures and Temperatures

In table 6 the results in table 1 have been converted to a temperature and pressure dependence by an equation of state. The new results were obtained by determining the density for a fixed pressure and temperature and then extracting the conductivity from table 1 by a logarithmic interpolation scheme. Similar results are tabulated for the other electrical conductivity calculation methods. Columns A and B of table 6 represent the coulombic contributions to the air conductivity as determined by equations (4) and (5), respectively. At the higher temperatures the effect of the charge-dependent impact parameter in the logarithm of $\sigma_{SH}$ is important. This effect increases with increasing temperature and decreases with increasing pressure. Column C is the electrical conductivity calculated using the present mixture rule but without the correction for small values of $ln(\overline{\Lambda}/|Z_i|)$. Columns D and E present small $ln(\overline{\Lambda}/|Z_i|)$ corrected results for the coulombic contribution to the conductivity, $\sigma_{SHU}$, and for the mixture rule, $\sigma_F$, respectively. A comparison of columns B with D and C with E reveals the magnitude of the small $ln(\overline{\Lambda}/|Z_i|)$ correction. The value of $\gamma_{UZ}(2)$ for these cases can be obtained by dividing numbers in column D by those in column B. This small $ln\ \overline{\Lambda}$ correction factor is negligible at the lower pressures and temperatures given here but becomes increasingly significant at the high temperatures as the pressure increases. At more moderate temperatures $\gamma_{UZ}$ is significant for all the pressures tabulated. The comparison of column B with D and C with E also illustrates how the dominant contributor to $\sigma_F$ varies from electron-neutral interactions to coulombic type interactions with increasing temperature. The results presented in column F are based on the previously mentioned modified Chapman-Enskog first approximation (table 2). They have not been corrected for small $ln(\overline{\Lambda}/|Z_i|)$ or charge-dependent impact-parameter effects and therefore are forced to agree with column A results when the gas is nearly fully ionized. (An unmodified Chapman-Enskog first approximation would yield a conductivity of only 0.506 $\sigma_{SH}$ when fully ionized. This result is apparent from equations (9) and (10) for large $ln(\overline{\Lambda}/|Z_i|)$.)

In addition, for ionic charges other than unity using equation (4) rather than (5) for $\sigma_{SH}$ leads to the disagreement between the mixture rule results of column C and those of column F when the gas is fully ionized.

At lower temperatures and consequently lower degrees of ionization, the mixture rule given by $\sigma_F$ becomes "exact." That is, $\sigma_F$ becomes identical to equation (1) which is an exact solution for the electrical conductivity in the limit of a weakly ionized gas. Hence, columns C and E of table 6 will agree with each other but will disagree considerably with results given in column F at low temperatures because the Chapman-Enskog first approximation to the electrical conductivity does not reduce to equation (1) in the weakly ionized limit. This same comment holds for higher Chapman-Enskog approximations (e.g., ref. 1 in which the twelfth approximation was employed).

In figure 2 the conductivity for pressures of 0.1 and 10.0 atmospheres is plotted from four sources for further comparison: Curves 1 correspond to the results in column E of table 6; curves 2 are based on column F; curves 3 are

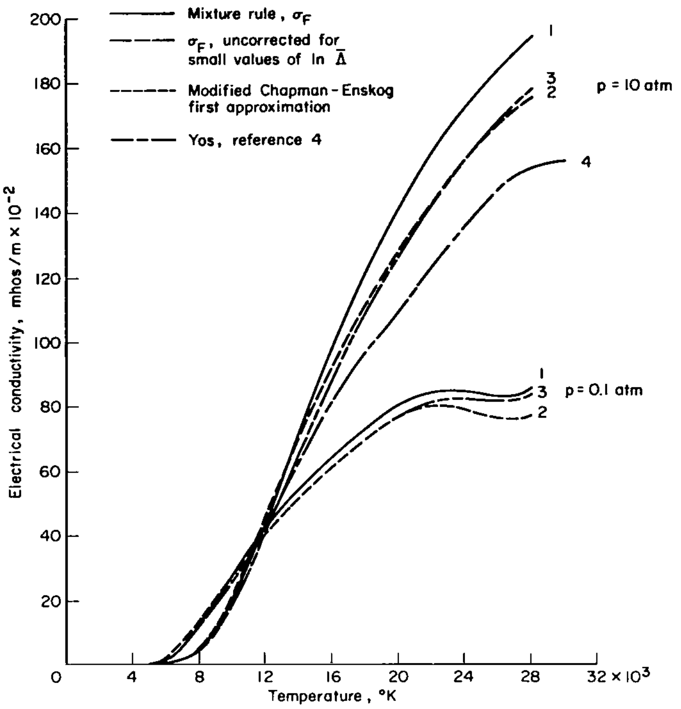


Figure 2.– Comparison of methods of calculating the electrical conductivity of equilibrium air at two pressures.

from column C; and curve 4 is taken from the well-used results in reference 4. The inflection at the higher temperatures of the low pressure curves corresponds to the region where the mean ionic charge increases rapidly with temperature from 1 to 2. The electrical conductivity in this region is therefore relatively insensitive to temperature changes. At the higher pressure, the gas is not yet fully doubly ionized; consequently, the conductivity is still sensitive to temperature changes at the highest temperatures shown. Curve 4 is included in the figure to illustrate the effects of some of the uncertainties (species, number densities, and cross sections) discussed previously.

## Additional Observations Regarding Conductivity Expressions

$\Gamma_{eI}/\Gamma_{ee}$ *vs.* Z- As previously discussed in regard to columns A and B of table 6, using the coulombic collision frequency ratio $\Gamma_{eI}/\Gamma_{ee}$ in the analysis rather than the mean ionic charge Z for the present range of conditions leads to differences in the value of $\sigma_{SH}$ of about 10 percent at low pressures and high temperatures. These differences result primarily from the second term on the right hand side of equation (6) rather than from $\gamma_E$ because $\gamma_E(\Gamma_{eI}/\Gamma_{ee})$ differs by only about 2 percent from $\gamma_E(Z)$, even though $\Gamma_{eI}/\Gamma_{ee}$ can differ by about 10 percent from Z. Furthermore, $\gamma_E$ changes with its argument to compensate somewhat for the effects of the argument changes [$\Gamma_{eI}/\Gamma_{ee}$ vs. Z] on $\sigma_{SH}$. These effects are illustrated when tables 7(a) and 7(b), and equation (14) are compared with table 3. When the small $ln\ \bar{\Lambda}$ corrections are negligible, these tables also delineate the regions where equation (4) can be applied, in lieu of the more complicated expression of equation (5), to determine $\sigma_{SH}$.

*Effect of small electron-neutral to coulombic collision frequency ratio-* When the gas is almost fully ionized, equation (9) for $\sigma_{SHU}$ should give results that agree with table 1. Values of $\sigma_{SHU}(2)$ are given in table 8 for equilibrium air. Based on a comparison of tables 8 and 1, one concludes that the conductivity behaves as if the gas were fully ionized at low pressures and

high temperatures. These results agree with references 6 and 23 in which it is shown that when $\nu_N/\nu_{ei} << 1$ the electrical conductivity of a plasma should be given by $\sigma_{SH}$.

In table 9 approximate values of $\nu_N/\nu_{ei}$ are tabulated as a function of density ratio. The collision frequency, $\nu_N$, is based on the mean effective collision cross section defined in references 4 and 24; and $\nu_{ei}$ is an effective collision frequency between electrons and the singly charged ions that is defined in references 3 and 4. It is apparent from tables 1, 8, and 9 that whenever $\nu_N/\nu_{ei} \lesssim 5\times10^{-3}$, the $\sigma_{SHU}(2)$ conductivity agrees with $\sigma_F$ within 2 percent. Since it is much easier to evaluate $\sigma_{SHU}(2)$ than $\sigma_F$ it is useful to know when one can rely solely upon equation (9) or (5), depending on size of $ln(\bar{\Lambda}/|Z_i|)$, to calculate the conductivity even though the gas may not be fully ionized.

*Effect of negatively charged ions*- As mentioned in the analysis section, it is possible to have $|Z_i| = 1$ while the mean ionic charge $Z$ is greater than unity. This situation occurs for air at high pressures and low temperatures when the number density of $O^-$ exceeds that of the electrons (ref. 14).[7] (See table 3.) Thus, the conservation of charge is satisfied but $n_e$ is not equal to $\sum_i n_i$ when summed over positive charges in this instance. For these cases the electrons have coulombic interactions with a larger number of particles than they would ordinarily if only positive charges existed. Hence, it is nearly as if the electrons were interacting with fewer species but each having a larger positive charge.

This larger effective mean ionic charge $Z$ diminishes the effect of electron-electron interactions because the cross section for coulombic collisions increases with $Z_i^2$. Hence, $\gamma_E \to 1$ and $C_F \to 5\sqrt{\pi}/16\gamma_{UZ}$. A similar result is mentioned in reference 7 where it is shown that as $Z \to \infty$, $\sigma_{SH}$ approaches the expression for a Lorentz gas.

## CONCLUDING REMARKS

The Frost mixture rule for calculating the electrical conductivity of partially ionized gases has been extended to apply to plasmas in which a varied mixture of neutrals and multiply ionized particles might exist. For effectively fully ionized plasmas, the Spitzer-Härm equation, modified (1) to include contributions of multiply ionized species to the impact parameter for large angle collisions and (2) to account for the effects of small values of $ln(\bar{\Lambda}/|Z_i|)$, remains valid and easy to apply. The usefulness of the mixture rule is especially apparent when the electrical conductivity must be determined over a wide range of ionization or temperature. For these cases, it is

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[7]Recent studies have indicated that $NO_2^-$ rather than $O^-$ is the dominant species in determining electron concentrations at these pressures and temperatures (ref. 25), and therefore should be included in any future calculations of this nature.

possible with one equation or computation procedure to obtain accurate conductivities over the entire range of the degree of ionization for various values of the mean ionic charge.

Although the results given are for air in thermal equilibrium, the equations used are applicable to the more general nonequipartition case. The species composition would have to be determined specifically for individual cases when the electron and gas temperatures are not the same.

The present calculations were not adequate for assessing the significance of the second term on the right hand side of equation (6) for a real gas. It was shown in the discussion of tables 3 and 7 that for the range of conditions calculated, this term could account for about 10 percent of $\sigma_{SH}$. At temperatures of the order $10^5$ °K, large numbers of multiply ionized species should exist. Extending the computation technique developed in the present report to these higher temperatures will provide an ample real gas test of the accuracy of equation (6) versus its truncated ($\Gamma_{eI} \approx Z\Gamma_{ee}$) version.

Finally, the theory of Spitzer-Härm (which leads to eq. (4)) becomes inaccurate for small values of $ln(\bar{\Lambda}/|Z_i|)$. Hence this parameter should be evaluated for each interaction for the density-temperature ranges under consideration to determine when small $ln\ \bar{\Lambda}$ corrections should be applied to subsequent calculations. While a method of treating such small $ln\ \bar{\Lambda}$ corrections has been illustrated and used in this paper, the method is by no means considered to be the last word on the subject. For example, in reference 1 two other small $ln\ \bar{\Lambda}$ correction procedures are presented for the $Z = 1$ case. The question of whether or not to include the effects of ion shielding in such a correction has not been resolved satisfactorily. Furthermore, there may be regions of interest in which the value of $ln(\bar{\Lambda}/|Z_i|)$ is even smaller than can be treated by these so-called small $ln\ \bar{\Lambda}$ correction procedures.

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Moffett Field, Calif., 94035, June 1, 1970

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TABLE 1.– ELECTRICAL CONDUCTIVITY (mhos/m) OF AIR IN THERMODYNAMIC EQUILIBRIUM BASED ON THE MIXTURE RULE FOR $\sigma_F$

| Temp., °K | Density ratios ($\rho/\rho_0$ where $\rho_0 = 1.225 \times 10^{-3}$ g/cm$^3$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10-6 | 10-5 | 10-4 | 10-3 | 10-2 | 10-1 | 10+0 | 10+1 | 10+2 |
| 3000 | 1.2760E-00 | 7.2803E-01 | 3.9816E-01 | 1.8560E-01 | 6.8695E-02 | 2.2632E-02 | 7.0847E-03 | 2.0966E-03 | 5.5717E-04 |
| 4000 | 3.5226E 01 | 2.3022E 01 | 1.4247E 01 | 8.4602E 00 | 4.7389E 00 | 2.2637E 00 | 8.3631E-01 | 2.5167E-01 | 6.3235E-02 |
| 6000 | 6.6219E 02 | 5.3767E 02 | 3.5213E 02 | 2.1106E 02 | 1.3839E 02 | 8.9242E 01 | 5.1588E 01 | 2.2811E 01 | 6.6189E 00 |
| 8000 | 1.4155E 03 | 1.5053E 03 | 1.5179E 03 | 1.3466E 03 | 9.4529E 02 | 5.2622E 02 | 3.0698E 02 | 1.7014E 02 | 6.4179E 01 |
| 10000 | 2.0736E 03 | 2.3796E 03 | 2.6433E 03 | 2.8110E 03 | 2.6930E 03 | 2.0845E 03 | 1.1878E 03 | 6.0761E 02 | 2.6583E 02 |
| 12000 | 2.6403E 03 | 3.1244E 03 | 3.6358E 03 | 4.2169E 03 | 4.6619E 03 | 4.3665E 03 | 3.2569E 03 | 1.7246E 03 | 6.8057E 02 |
| 14000 | 3.2239E 03 | 3.8394E 03 | 4.6288E 03 | 5.6544E 03 | 6.7038E 03 | 7.2208E 03 | 6.2921E 03 | 4.1475E 03 | 1.6036E 03 |
| 16000 | 3.6735E 03 | 4.5060E 03 | 5.4872E 03 | 6.7942E 03 | 8.5224E 03 | 9.9715E 03 | 1.0113E 04 | 8.4552E 03 | 3.2211E 03 |
| 18000 | 3.5794E 03 | 5.0364E 03 | 6.2814E 03 | 7.8615E 03 | 1.0198E 04 | 1.2836E 04 | 1.4503E 04 | 1.6919E 04 | 5.3569E 03 |
| 20000 | 3.6070E 03 | 4.9855E 03 | 6.8684E 03 | 8.9026E 03 | 1.1714E 04 | 1.5556E 04 | 1.9108E 04 | 1.3857E 04 | 8.1911E 03 |
| 22000 | 3.8746E 03 | 4.9043E 03 | 7.0273E 03 | 9.8742E 03 | 1.3128E 04 | 1.7916E 04 | 2.4141E 04 | 1.7911E 04 | 1.1636E 04 |
| 24000 | 4.3097E 03 | 5.1588E 03 | 7.0355E 03 | 1.0399E 04 | 1.4383E 04 | 2.0132E 04 | 2.8630E 04 | 2.2295E 04 | 1.5308E 04 |
| 26000 | 4.6962E 03 | 5.6290E 03 | 7.2276E 03 | 1.0358E 04 | 1.5354E 04 | 2.2112E 04 | 3.2590E 04 | 2.6940E 04 | 1.9480E 04 |
| 28000 | 5.0688E 03 | 6.0736E 03 | 7.5727E 03 | 1.0878E 04 | 1.6126E 04 | 2.4254E 04 | 3.6474E 04 | 3.1352E 04 | 2.3993E 04 |

TABLE 2.– ELECTRICAL CONDUCTIVITY (mhos/m) OF AIR IN THERMODYNAMIC EQUILIBRIUM BASED ON THE MODIFIED CHAPMAN–ENSKOG FIRST APPROXIMATION

| Temp., °K | Density ratios ($\rho/\rho_0$ where $\rho_0 = 1.225 \times 10^{-3}$ g/cm$^3$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10-6 | 10-5 | 10-4 | 10-3 | 10-2 | 10-1 | 10+0 | 10+1 | 10+2 |
| 3000 | 9.8307E-01 | 5.5041E-01 | 2.9769E-01 | 1.3909E-01 | 5.2044E-02 | 1.7257E-02 | 5.4152E-03 | 1.6038E-03 | 4.2630E-04 |
| 4000 | 3.2966E 01 | 1.9750E 01 | 1.1426E 01 | 6.4557E 00 | 3.4941E 00 | 1.6414E 00 | 6.0512E-01 | 1.8222E-01 | 4.5785E-02 |
| 6000 | 7.0634E 02 | 6.1444E 02 | 4.1256E 02 | 2.2424E 02 | 1.2595E 02 | 7.1613E 01 | 3.8079E 01 | 1.6178E 01 | 4.6273E 00 |
| 8000 | 1.3976E 03 | 1.4995E 03 | 1.5613E 03 | 1.4805E 03 | 1.1020E 03 | 5.7935E 02 | 2.8903E 02 | 1.4184E 02 | 5.0813E 01 |
| 10000 | 2.0343E 03 | 2.3223E 03 | 2.5830E 03 | 2.8013E 03 | 2.8374E 03 | 2.3541E 03 | 1.3093E 03 | 5.7142E 02 | 2.1969E 02 |
| 12000 | 2.5918E 03 | 3.0463E 03 | 3.5008E 03 | 4.0599E 03 | 4.6031E 03 | 4.6313E 03 | 3.7308E 03 | 1.8952E 03 | 6.8080E 02 |
| 14000 | 3.1691E 03 | 3.7546E 03 | 4.4714E 03 | 5.3877E 03 | 6.3838E 03 | 7.0880E 03 | 6.5118E 03 | 4.2102E 03 | 1.6630E 03 |
| 16000 | 3.5941E 03 | 4.4032E 03 | 5.3100E 03 | 6.4573E 03 | 7.9651E 03 | 9.3467E 03 | 9.7735E 03 | 7.6067E 03 | 3.4898E 03 |
| 18000 | 3.4114E 03 | 4.9025E 03 | 6.0764E 03 | 7.4814E 03 | 9.4776E 03 | 1.1724E 04 | 1.3221E 04 | 1.1624E 04 | 5.9171E 03 |
| 20000 | 3.3690E 03 | 4.7389E 03 | 6.5993E 03 | 8.4854E 03 | 1.0894E 04 | 1.3990E 04 | 1.6610E 04 | 1.6163E 04 | 9.1670E 03 |
| 22000 | 3.5886E 03 | 4.5422E 03 | 6.6332E 03 | 9.4040E 03 | 1.2226E 04 | 1.6009E 04 | 2.0190E 04 | 2.0705E 04 | 1.3158E 04 |
| 24000 | 3.9922E 03 | 4.7299E 03 | 6.5037E 03 | 9.7864E 03 | 1.3402E 04 | 1.7973E 04 | 2.3438E 04 | 2.5532E 04 | 1.7438E 04 |
| 26000 | 4.3388E 03 | 5.1526E 03 | 6.5850E 03 | 9.5223E 03 | 1.4225E 04 | 1.9772E 04 | 2.6491E 04 | 3.0631E 04 | 2.2337E 04 |
| 28000 | 4.6769E 03 | 5.5474E 03 | 6.8417E 03 | 9.8927E 03 | 1.4777E 04 | 2.1722E 04 | 2.9501E 04 | 3.5409E 04 | 2.7697E 04 |

## TABLE 3.– MEAN IONIC CHARGE Z OF EQUILIBRIUM AIR

Density ratios ($\rho/\rho_0$ where $\rho_0 = 1.225 \times 10^{-3}$ g/cm$^3$)

| Temp., °K | 10-6 | 10-5 | 10-4 | 10-3 | 10-2 | 10-1 | 10+0 | 10+1 | 10+2 |
|---|---|---|---|---|---|---|---|---|---|
| 3000 | 1.0011E 00 | 1.0005E 00 | 1.0000E 00 | 1.0011E 00 | 1.0126E 00 | 1.0219E 00 | 1.1500E 00 | 1.4797E 00 | 2.5216E 00 |
| 4000 | 9.9967E-01 | 9.9959E-01 | 1.0003E 00 | 1.0013E 00 | 1.0059E 00 | 1.0478E 00 | 1.2165E 00 | 1.7913E 00 | 3.6146E 00 |
| 6000 | 9.9886E-01 | 1.0014E 00 | 9.9977E-01 | 1.0001E 00 | 1.0009E 00 | 1.0092E 00 | 1.0840E 00 | 1.5803E 00 | 3.7488E 00 |
| 8000 | 9.9993E-01 | 1.0000E 00 | 9.9998E-01 | 1.0000E 00 | 1.0003E 00 | 1.0035E 00 | 1.0307E 00 | 1.2658E 00 | 2.7521E 00 |
| 10000 | 9.9985E-01 | 9.9994E-01 | 9.9989E-01 | 1.0000E 00 | 1.0005E 00 | 1.0016E 00 | 1.0152E 00 | 1.1401E 00 | 2.0918E 00 |
| 12000 | 1.0021E 00 | 9.9655E-01 | 1.0163E 00 | 1.0109E 00 | 9.9630E-01 | 1.0056E 00 | 1.0212E 00 | 1.0925E 00 | 1.6773E 00 |
| 14000 | 1.0042E 00 | 9.8964E-01 | 9.9342E-01 | 9.9558E-01 | 9.8457E-01 | 9.8073E-01 | 1.0223E 00 | 1.0679E 00 | 1.4626E 00 |
| 16000 | 1.0797E 00 | 1.0050E 00 | 9.9367E-01 | 1.0018E 00 | 1.0001E 00 | 1.0005E 00 | 1.0150E 00 | 1.0421E 00 | 1.3440E 00 |
| 18000 | 1.4503E 00 | 1.0793E 00 | 1.0095E 00 | 1.0046E 00 | 1.0023E 00 | 9.9802E-01 | 1.0035E 00 | 1.0283E 00 | 1.2850E 00 |
| 20000 | 1.7912E 00 | 1.3750E 00 | 1.0825E 00 | 1.0110E 00 | 1.0011E 00 | 9.9946E-01 | 1.0035E 00 | 1.0175E 00 | 1.2316E 00 |
| 22000 | 1.9485E 00 | 1.7265E 00 | 1.2853E 00 | 1.0371E 00 | 1.0054E 00 | 1.0047E 00 | 9.9889E-01 | 1.0208E 00 | 1.1814E 00 |
| 24000 | 1.9812E 00 | 1.9052E 00 | 1.5519E 00 | 1.1450E 00 | 1.0203E 00 | 1.0059E 00 | 1.0019E 00 | 1.0200E 00 | 1.1608E 00 |
| 26000 | 2.0367E 00 | 1.9642E 00 | 1.7648E 00 | 1.3631E 00 | 1.0703E 00 | 1.0101E 00 | 1.0034E 00 | 1.0116E 00 | 1.1274E 00 |
| 28000 | 2.1118E 00 | 2.0182E 00 | 1.9002E 00 | 1.5127E 00 | 1.1558E 00 | 1.0094E 00 | 1.0071E 00 | 1.0078E 00 | 1.0897E 00 |

## TABLE 4.– VALUES OF $\ln \bar{\Lambda}$ FOR EQUILIBRIUM AIR

Density ratios ($\rho/\rho_0$ where $\rho_0 = 1.225 \times 10^{-3}$ g/cm$^3$)

| Temp., °K | 10-6 | 10-5 | 10-4 | 10-3 | 10-2 | 10-1 | 10+0 | 10+1 | 10+2 |
|---|---|---|---|---|---|---|---|---|---|
| 3000 | 1.2728E 01 | 1.1868E 01 | 1.1023E 01 | 1.0246E 01 | 9.5788E 00 | 8.9751E 00 | 8.4022E 00 | 7.8589E 00 | 7.3697E 00 |
| 4000 | 1.1230E 01 | 1.0347E 01 | 9.4789E 00 | 8.6184E 00 | 7.7760E 00 | 7.0009E 00 | 6.3453E 00 | 5.7922E 00 | 5.3313E 00 |
| 6000 | 9.1194E 00 | 8.5392E 00 | 7.9332E 00 | 7.2073E 00 | 6.3564E 00 | 5.4935E 00 | 4.6655E 00 | 3.9488E 00 | 3.4282E 00 |
| 8000 | 7.7922E 00 | 7.1636E 00 | 6.5710E 00 | 5.9892E 00 | 5.4037E 00 | 4.7585E 00 | 3.9797E 00 | 3.1892E 00 | 2.5585E 00 |
| 10000 | 7.5159E 00 | 6.5698E 00 | 5.8551E 00 | 5.2296E 00 | 4.6381E 00 | 4.0545E 00 | 3.4467E 00 | 2.7449E 00 | 2.0675E 00 |
| 12000 | 7.7396E 00 | 6.6197E 00 | 5.6373E 00 | 4.8400E 00 | 4.1767E 00 | 3.6010E 00 | 3.0133E 00 | 2.4006E 00 | 1.7729E 00 |
| 14000 | 7.9683E 00 | 6.8170E 00 | 5.6997E 00 | 4.7023E 00 | 3.9356E 00 | 3.2990E 00 | 2.7040E 00 | 2.1157E 00 | 1.5137E 00 |
| 16000 | 8.1512E 00 | 7.0123E 00 | 5.8661E 00 | 4.7766E 00 | 3.8412E 00 | 3.1269E 00 | 2.5007E 00 | 1.9116E 00 | 1.3226E 00 |
| 18000 | 8.2120E 00 | 7.1646E 00 | 6.0402E 00 | 4.9121E 00 | 3.8658E 00 | 3.0462E 00 | 2.3771E 00 | 1.7740E 00 | 1.1975E 00 |
| 20000 | 8.2479E 00 | 7.2415E 00 | 6.1858E 00 | 5.0546E 00 | 3.9556E 00 | 3.0253E 00 | 2.3095E 00 | 1.6747E 00 | 1.1031E 00 |
| 22000 | 8.3330E 00 | 7.2628E 00 | 6.2666E 00 | 5.1824E 00 | 4.0595E 00 | 3.0590E 00 | 2.2664E 00 | 1.6160E 00 | 1.0341E 00 |
| 24000 | 8.4316E 00 | 7.3336E 00 | 6.3063E 00 | 5.2795E 00 | 4.1792E 00 | 3.1179E 00 | 2.2633E 00 | 1.5842E 00 | 9.9382E-01 |
| 26000 | 8.5429E 00 | 7.4131E 00 | 6.3419E 00 | 5.3468E 00 | 4.2838E 00 | 3.1969E 00 | 2.2875E 00 | 1.5677E 00 | 9.6021E-01 |
| 28000 | 8.6344E 00 | 7.5178E 00 | 6.4093E 00 | 5.3634E 00 | 4.3683E 00 | 3.2733E 00 | 2.3145E 00 | 1.5680E 00 | 9.4399E-01 |

TABLE 5.– VALUES OF SMALL $ln(\bar{\Lambda}/|Z_i|)$ CORRECTION FACTOR $\gamma_{UZ}(2)$ FOR EQUILIBRIUM AIR

| Temp., °K | Density ratios ($\rho/\rho_o$ where $\rho_o = 1.225 \times 10^{-3}$ g/cm$^3$) 10-6 | 10-5 | 10-4 | 10-3 | 10-2 | 10-1 | 10+0 | 10+1 | 10+2 |
|---|---|---|---|---|---|---|---|---|---|
| 3000 | 1.0005E 00 | 1.0024E 00 | 1.0045E 00 | 1.0067E 00 | 1.0079E 00 | 1.0095E 00 | 1.0060E 00 | 1.0074E 00 | 1.0090E 00 |
| 4000 | 1.0040E 00 | 1.0065E 00 | 1.0095E 00 | 1.0131E 00 | 1.0172E 00 | 1.0186E 00 | 1.0166E 00 | 1.0166E 00 | 9.9541E-01 |
| 6000 | 1.0111E 00 | 1.0135E 00 | 1.0169E 00 | 1.0217E 00 | 1.0290E 00 | 1.0386E 00 | 1.0456E 00 | 1.0407E 00 | 9.9532E-01 |
| 8000 | 1.0177E 00 | 1.0220E 00 | 1.0270E 00 | 1.0332E 00 | 1.0412E 00 | 1.0530E 00 | 1.0717E 00 | 1.0871E 00 | 1.0545E 00 |
| 10000 | 1.0195E 00 | 1.0271E 00 | 1.0349E 00 | 1.0442E 00 | 1.0563E 00 | 1.0737E 00 | 1.1008E 00 | 1.1480E 00 | 1.2644E 00 |
| 12000 | 1.0178E 00 | 1.0270E 00 | 1.0357E 00 | 1.0501E 00 | 1.0703E 00 | 1.0935E 00 | 1.1359E 00 | 1.2373E 00 | 1.0000E 00 |
| 14000 | 1.0163E 00 | 1.0262E 00 | 1.0379E 00 | 1.0556E 00 | 1.0818E 00 | 1.1192E 00 | 1.1794E 00 | 1.4118E 00 | 1.0000E 00 |
| 16000 | 1.0106E 00 | 1.0229E 00 | 1.0357E 00 | 1.0528E 00 | 1.0827E 00 | 1.1291E 00 | 1.2280E 00 | 1.8167E 00 | 1.0000E 00 |
| 18000 | 1.0065E 00 | 1.0171E 00 | 1.0319E 00 | 1.0496E 00 | 1.0812E 00 | 1.1379E 00 | 1.2735E 00 | 3.2376E 00 | 1.0000E 00 |
| 20000 | 1.0081E 00 | 1.0111E 00 | 1.0253E 00 | 1.0463E 00 | 1.0777E 00 | 1.1398E 00 | 1.3032E 00 | 1.0000E 00 | 1.0000E 00 |
| 22000 | 1.0086E 00 | 1.0112E 00 | 1.0190E 00 | 1.0425E 00 | 1.0734E 00 | 1.1351E 00 | 1.3276E 00 | 1.0000E 00 | 1.0000E 00 |
| 24000 | 1.0085E 00 | 1.0113E 00 | 1.0169E 00 | 1.0351E 00 | 1.0681E 00 | 1.1293E 00 | 1.3285E 00 | 1.0000E 00 | 1.0000E 00 |
| 26000 | 1.0084E 00 | 1.0111E 00 | 1.0162E 00 | 1.0286E 00 | 1.0610E 00 | 1.1222E 00 | 1.3154E 00 | 1.0000E 00 | 1.0000E 00 |
| 28000 | 1.0085E 00 | 1.0108E 00 | 1.0155E 00 | 1.0274E 00 | 1.0551E 00 | 1.1185E 00 | 1.3021E 00 | 1.0000E 00 | 1.0000E 00 |

TABLE 6.– ELECTRICAL CONDUCTIVITY OF EQUILIBRIUM AIR AT NUMEROUS PRESSURES AND TEMPERATURES CALCULATED ACCORDING TO METHODS DESCRIBED IN THE TEXT

(a) Pressure = 0.1 atm

| Temperature, °K | Density ratio | [a]Electrical conductivity, mhos/m | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| 0.3000E 04 | 0.8715E-02 | 0.2594E 03 | 0.2594E 03 | 0.7568E-01 | 0.2614E 03 | 0.7568E-01 | 0.5724E-01 |
| 0.4000E 04 | 0.5991E-02 | 0.4853E 03 | 0.4853E 03 | 0.5562E 01 | 0.4932E 03 | 0.5567E 01 | 0.4153E 01 |
| 0.6000E 04 | 0.3134E-02 | 0.1052E 04 | 0.1052E 04 | 0.1737E 03 | 0.1079E 04 | 0.1750E 03 | 0.1755E 03 |
| 0.8000E 04 | 0.1824E-02 | 0.1879E 04 | 0.1879E 04 | 0.1213E 04 | 0.1946E 04 | 0.1242E 04 | 0.1382E 04 |
| 0.1000E 05 | 0.1341E-02 | 0.2973E 04 | 0.2973E 04 | 0.2685E 04 | 0.3109E 04 | 0.2796E 04 | 0.2806E 04 |
| 0.1200E 05 | 0.9102E-03 | 0.4101E 04 | 0.4101E 04 | 0.4000E 04 | 0.4304E 04 | 0.4193E 04 | 0.4037E 04 |
| 0.1400E 05 | 0.5973E-03 | 0.5194E 04 | 0.5194E 04 | 0.5158E 04 | 0.5465E 04 | 0.5425E 04 | 0.5183E 04 |
| 0.1600E 05 | 0.4705E-03 | 0.6090E 04 | 0.6090E 04 | 0.6076E 04 | 0.6382E 04 | 0.6366E 04 | 0.6082E 04 |
| 0.1800E 05 | 0.4064E-03 | 0.6943E 04 | 0.6948E 04 | 0.6942E 04 | 0.7251E 04 | 0.7244E 04 | 0.6932E 04 |
| 0.2000E 05 | 0.3592E-03 | 0.7665E 04 | 0.7707E 04 | 0.7704E 04 | 0.8002E 04 | 0.7998E 04 | 0.7647E 04 |
| 0.2200E 05 | 0.3135E-03 | 0.8007E 04 | 0.8177E 04 | 0.8174E 04 | 0.8442E 04 | 0.8440E 04 | 0.8008E 04 |
| 0.2400E 05 | 0.2661E-03 | 0.7891E 04 | 0.8250E 04 | 0.8248E 04 | 0.8467E 04 | 0.8465E 04 | 0.7899E 04 |
| 0.2600E 05 | 0.2246E-03 | 0.7612E 04 | 0.8154E 04 | 0.8152E 04 | 0.8329E 04 | 0.8328E 04 | 0.7617E 04 |
| 0.2800E 05 | 0.1931E-03 | 0.7688E 04 | 0.8354E 04 | 0.8352E 04 | 0.8520E 04 | 0.8517E 04 | 0.7714E 04 |
| | | | (b) Pressure = 0.2 atm | | | | |
| 0.3000E 04 | 0.1746E-01 | 0.2641E 03 | 0.2641E 03 | 0.5754E-01 | 0.2663E 03 | 0.5754E-01 | 0.4362E-01 |
| 0.4000E 04 | 0.1201E-01 | 0.4989E 03 | 0.4989E 03 | 0.4539E 01 | 0.5076E 03 | 0.4542E 01 | 0.3347E 01 |
| 0.6000E 04 | 0.6646E-02 | 0.1095E 04 | 0.1095E 04 | 0.1502E 03 | 0.1125E 04 | 0.1513E 03 | 0.1434E 03 |
| 0.8000E 04 | 0.3707E-02 | 0.1940E 04 | 0.1940E 04 | 0.1093E 04 | 0.2014E 04 | 0.1118E 04 | 0.1265E 04 |
| 0.1000E 05 | 0.2727E-02 | 0.3087E 04 | 0.3087E 04 | 0.2647E 04 | 0.3241E 04 | 0.2760E 04 | 0.2817E 04 |
| 0.1200E 05 | 0.1919E-02 | 0.4324E 04 | 0.4324E 04 | 0.4123E 04 | 0.4568E 04 | 0.4343E 04 | 0.4214E 04 |
| 0.1400E 05 | 0.1259E-02 | 0.5515E 04 | 0.5515E 04 | 0.5445E 04 | 0.5838E 04 | 0.5760E 04 | 0.5488E 04 |
| 0.1600E 05 | 0.9545E-03 | 0.6450E 04 | 0.6450E 04 | 0.6431E 04 | 0.6789E 04 | 0.6768E 04 | 0.6434E 04 |
| 0.1800E 05 | 0.8192E-03 | 0.7375E 04 | 0.7378E 04 | 0.7369E 04 | 0.7734E 04 | 0.7725E 04 | 0.7360E 04 |
| 0.2000E 05 | 0.7260E-03 | 0.8238E 04 | 0.8262E 04 | 0.8257E 04 | 0.8625E 04 | 0.8620E 04 | 0.8223E 04 |
| 0.2200E 05 | 0.6432E-03 | 0.8870E 04 | 0.8981E 04 | 0.8978E 04 | 0.9332E 04 | 0.9328E 04 | 0.8873E 04 |
| 0.2400E 05 | 0.5577E-03 | 0.8954E 04 | 0.9256E 04 | 0.9253E 04 | 0.9549E 04 | 0.9546E 04 | 0.8954E 04 |
| 0.2600E 05 | 0.4759E-03 | 0.8585E 04 | 0.9118E 04 | 0.9116E 04 | 0.9350E 04 | 0.9348E 04 | 0.8575E 04 |
| 0.2800E 05 | 0.4069E-03 | 0.8647E 04 | 0.9368E 04 | 0.9365E 04 | 0.9590E 04 | 0.9587E 04 | 0.8701E 04 |

[a]Columns A through F correspond, respectively, to calculations based on $\sigma_{SH}$ (eq. (4)), $\sigma_{SH}$ (eq. (5)), $\sigma_F$ (without small $ln(\Lambda/|Z_i|)$ correction), $\sigma_{SHU}$, $\sigma_F$ (with small $ln(\Lambda/|Z_i|)$ correction), and the modified Chapman-Enskog first approximation.

TABLE 6.– ELECTRICAL CONDUCTIVITY OF EQUILIBRIUM AIR AT NUMEROUS PRESSURES AND TEMPERATURES CALCULATED ACCORDING TO METHODS DESCRIBED IN THE TEXT – Continued

(c) Pressure = 0.3 atm

| Temperature, °K | Density ratio | [a]Electrical conductivity, mhos/m | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| 0.3000E 04 | 0.2620E-01 | 0.2669E 03 | 0.2669E 03 | 0.4943E-01 | 0.2692E 03 | 0.4943E-01 | 0.3749E-01 |
| 0.4000E 04 | 0.1801E-01 | 0.5060E 03 | 0.5060E 03 | 0.4103E 01 | 0.5149E 03 | 0.4106E 01 | 0.3021E 01 |
| 0.6000E 04 | 0.1030E-01 | 0.1120E 04 | 0.1120E 04 | 0.1368E 03 | 0.1153E 04 | 0.1378E 03 | 0.1253E 03 |
| 0.8000E 04 | 0.5613E-02 | 0.1976E 04 | 0.1976E 04 | 0.1023E 04 | 0.2054E 04 | 0.1046E 04 | 0.1197E 04 |
| 0.1000E 05 | 0.4131E-02 | 0.3154E 04 | 0.3154E 04 | 0.2625E 04 | 0.3318E 04 | 0.2738E 04 | 0.2824E 04 |
| 0.1200E 05 | 0.2960E-02 | 0.4456E 04 | 0.4456E 04 | 0.4191E 04 | 0.4725E 04 | 0.4427E 04 | 0.4316E 04 |
| 0.1400E 05 | 0.1983E-02 | 0.5732E 04 | 0.5731E 04 | 0.5615E 04 | 0.6101E 04 | 0.5966E 04 | 0.5684E 04 |
| 0.1600E 05 | 0.1482E-02 | 0.6745E 04 | 0.6745E 04 | 0.6699E 04 | 0.7142E 04 | 0.7089E 04 | 0.6715E 04 |
| 0.1800E 05 | 0.1244E-02 | 0.7692E 04 | 0.7694E 04 | 0.7676E 04 | 0.8104E 04 | 0.8083E 04 | 0.7671E 04 |
| 0.2000E 05 | 0.1097E-02 | 0.8596E 04 | 0.8611E 04 | 0.8603E 04 | 0.9023E 04 | 0.9015E 04 | 0.8582E 04 |
| 0.2200E 05 | 0.9792E-03 | 0.9375E 04 | 0.9452E 04 | 0.9448E 04 | 0.9852E 04 | 0.9848E 04 | 0.9379E 04 |
| 0.2400E 05 | 0.8597E-03 | 0.9576E 04 | 0.9844E 04 | 0.9841E 04 | 0.1018E 05 | 0.1018E 05 | 0.9571E 04 |
| 0.2600E 05 | 0.7383E-03 | 0.9154E 04 | 0.9682E 04 | 0.9680E 04 | 0.9947E 04 | 0.9945E 04 | 0.9135E 04 |
| 0.2800E 05 | 0.6293E-03 | 0.9207E 04 | 0.9961E 04 | 0.9958E 04 | 0.1022E 05 | 0.1021E 05 | 0.9279E 04 |

(d) Pressure = 0.4 atm

| Temperature, °K | Density ratio | A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|
| 0.3000E 04 | 0.3493E-01 | 0.2689E 03 | 0.2689E 03 | 0.4367E-01 | 0.2712E 03 | 0.4367E-01 | 0.3315E-01 |
| 0.4000E 04 | 0.2401E-01 | 0.5109E 03 | 0.5109E 03 | 0.3794E 01 | 0.5200E 03 | 0.3797E 01 | 0.2789E 01 |
| 0.6000E 04 | 0.1387E-01 | 0.1142E 04 | 0.1142E 04 | 0.1305E 03 | 0.1177E 04 | 0.1314E 03 | 0.1182E 03 |
| 0.8000E 04 | 0.7535E-02 | 0.2001E 04 | 0.2001E 04 | 0.9728E 03 | 0.2082E 04 | 0.9946E 03 | 0.1149E 04 |
| 0.1000E 05 | 0.5546E-02 | 0.3202E 04 | 0.3202E 04 | 0.2609E 04 | 0.3373E 04 | 0.2723E 04 | 0.2828E 04 |
| 0.1200E 05 | 0.4026E-02 | 0.4549E 04 | 0.4549E 04 | 0.4239E 04 | 0.4836E 04 | 0.4486E 04 | 0.4388E 04 |
| 0.1400E 05 | 0.2736E-02 | 0.5885E 04 | 0.5885E 04 | 0.5735E 04 | 0.6287E 04 | 0.6113E 04 | 0.5823E 04 |
| 0.1600E 05 | 0.2029E-02 | 0.6961E 04 | 0.6961E 04 | 0.6894E 04 | 0.7403E 04 | 0.7325E 04 | 0.6921E 04 |
| 0.1800E 05 | 0.1683E-02 | 0.7960E 04 | 0.7962E 04 | 0.7931E 04 | 0.8424E 04 | 0.8389E 04 | 0.7032E 04 |
| 0.2000E 05 | 0.1472E-02 | 0.8907E 04 | 0.8920E 04 | 0.8906E 04 | 0.9391E 04 | 0.9375E 04 | 0.8890E 04 |
| 0.2200E 05 | 0.1312E-02 | 0.9736E 04 | 0.9804E 04 | 0.9797E 04 | 0.1027E 05 | 0.1026E 05 | 0.9737E 04 |
| 0.2400E 05 | 0.1161E-02 | 0.1003E 05 | 0.1027E 05 | 0.1027E 05 | 0.1066E 05 | 0.1066E 05 | 0.1002E 05 |
| 0.2600E 05 | 0.1008E-02 | 0.9563E 04 | 0.1009E 05 | 0.1009E 05 | 0.1038E 05 | 0.1037E 05 | 0.9538E 04 |
| 0.2800E 05 | 0.8574E-03 | 0.9605E 04 | 0.1038E 05 | 0.1038E 05 | 0.1066E 05 | 0.1066E 05 | 0.9689E 04 |

[a]See footnote, page 19.

TABLE 6.– ELECTRICAL CONDUCTIVITY OF EQUILIBRIUM AIR AT NUMEROUS PRESSURES AND TEMPERATURES CALCULATED ACCORDING TO METHODS DESCRIBED IN THE TEXT – Continued

(e) Pressure = 0.5 atm

| Temperature, °K | Density ratio | [a]Electrical conductivity, mhos/m | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| 0.3000E 04 | 0.4366E-01 | 0.2704E 03 | 0.2704E 03 | 0.3921E-01 | 0.2728E 03 | 0.3921E-01 | 0.2978E-01 |
| 0.4000E 04 | 0.3002E-01 | 0.5148E 03 | 0.5148E 03 | 0.3555E 01 | 0.5240E 03 | 0.3557E 01 | 0.2610E 01 |
| 0.6000E 04 | 0.1746E-01 | 0.1159E 04 | 0.1159E 04 | 0.1256E 03 | 0.1195E 04 | 0.1265E 03 | 0.1128E 03 |
| 0.8000E 04 | 0.9467E-02 | 0.2021E 04 | 0.2021E 04 | 0.9342E 03 | 0.2104E 04 | 0.9548E 03 | 0.1111E 04 |
| 0.1000E 05 | 0.6969E-02 | 0.3239E 04 | 0.3239E 04 | 0.2597E 04 | 0.3416E 04 | 0.2712E 04 | 0.2832E 04 |
| 0.1200E 05 | 0.5110E-02 | 0.4622E 04 | 0.4622E 04 | 0.4277E 04 | 0.4923E 04 | 0.4532E 04 | 0.4445E 04 |
| 0.1400E 05 | 0.3513E-02 | 0.6004E 04 | 0.6004E 04 | 0.5828E 04 | 0.6431E 04 | 0.6227E 04 | 0.5931E 04 |
| 0.1600E 05 | 0.2590E-02 | 0.7129E 04 | 0.7129E 04 | 0.7046E 04 | 0.7605E 04 | 0.7508E 04 | 0.7080E 04 |
| 0.1800E 05 | 0.2127E-02 | 0.8168E 04 | 0.8169E 04 | 0.8129E 04 | 0.8673E 04 | 0.8627E 04 | 0.8135E 04 |
| 0.2000E 05 | 0.1849E-02 | 0.9148E 04 | 0.9160E 04 | 0.9140E 04 | 0.9676E 04 | 0.9653E 04 | 0.9128E 04 |
| 0.2200E 05 | 0.1645E-02 | 0.1002E 05 | 0.1008E 05 | 0.1007E 05 | 0.1059E 05 | 0.1058E 05 | 0.1001E 05 |
| 0.2400E 05 | 0.1458E-02 | 0.1039E 05 | 0.1061E 05 | 0.1061E 05 | 0.1106E 05 | 0.1105E 05 | 0.1038E 05 |
| 0.2600E 05 | 0.1272E-02 | 0.1004E 05 | 0.1053E 05 | 0.1053E 05 | 0.1088E 05 | 0.1088E 05 | 0.1001E 05 |
| 0.2800E 05 | 0.1089E-02 | 0.9988E 04 | 0.1076E 05 | 0.1076E 05 | 0.1108E 05 | 0.1107E 05 | 0.1007E 05 |

(f) Pressure = 0.6 atm

| Temperature, °K | Density ratio | A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|
| 0.3000E 04 | 0.5239E-01 | 0.2716E 03 | 0.2716E 03 | 0.3556E-01 | 0.2741E 03 | 0.3556E-01 | 0.2702E-01 |
| 0.4000E 04 | 0.3602E-01 | 0.5180E 03 | 0.5180E 03 | 0.3359E 01 | 0.5273E 03 | 0.3361E 01 | 0.2463E 01 |
| 0.6000E 04 | 0.2108E-01 | 0.1173E 04 | 0.1173E 04 | 0.1216E 03 | 0.1211E 04 | 0.1225E 03 | 0.1084E 03 |
| 0.8000E 04 | 0.1145E-01 | 0.2041E 04 | 0.2041E 04 | 0.9010E 03 | 0.2127E 04 | 0.9207E 03 | 0.1071E 04 |
| 0.1000E 05 | 0.8400E-02 | 0.3269E 04 | 0.3269E 04 | 0.2587E 04 | 0.3450E 04 | 0.2702E 04 | 0.2835E 04 |
| 0.1200E 05 | 0.6210E-02 | 0.4681E 04 | 0.4681E 04 | 0.4307E 04 | 0.4993E 04 | 0.4570E 04 | 0.4491E 04 |
| 0.1400E 05 | 0.4308E-02 | 0.6102E 04 | 0.6102E 04 | 0.5904E 04 | 0.6549E 04 | 0.6320E 04 | 0.6020E 04 |
| 0.1600E 05 | 0.3161E-02 | 0.7266E 04 | 0.7266E 04 | 0.7170E 04 | 0.7771E 04 | 0.7658E 04 | 0.7211E 04 |
| 0.1800E 05 | 0.2575E-02 | 0.8338E 04 | 0.8339E 04 | 0.8291E 04 | 0.8876E 04 | 0.8821E 04 | 0.8301E 04 |
| 0.2000E 05 | 0.2229E-02 | 0.9345E 04 | 0.9356E 04 | 0.9332E 04 | 0.9909E 04 | 0.9881E 04 | 0.9324E 04 |
| 0.2200E 05 | 0.1979E-02 | 0.1025E 05 | 0.1030E 05 | 0.1029E 05 | 0.1085E 05 | 0.1084E 05 | 0.1024E 05 |
| 0.2400E 05 | 0.1757E-02 | 0.1068E 05 | 0.1089E 05 | 0.1088E 05 | 0.1138E 05 | 0.1137E 05 | 0.1067E 05 |
| 0.2600E 05 | 0.1539E-02 | 0.1044E 05 | 0.1090E 05 | 0.1089E 05 | 0.1130E 05 | 0.1129E 05 | 0.1040E 05 |
| 0.2800E 05 | 0.1321E-02 | 0.1041E 05 | 0.1116E 05 | 0.1116E 05 | 0.1152E 05 | 0.1151E 05 | 0.1048E 05 |

[a]See footnote, page 19.

TABLE 6.– ELECTRICAL CONDUCTIVITY OF EQUILIBRIUM AIR AT NUMEROUS PRESSURES AND TEMPERATURES CALCULATED ACCORDING TO METHODS DESCRIBED IN THE TEXT – Continued

(g) Pressure = 0.7 atm

| Temperature, °K | Density ratio | [a]Electrical conductivity, mhos/m | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| 0.3000E 04 | 0.6113E-01 | 0.2727E 03 | 0.2727E 03 | 0.3248E-01 | 0.2752E 03 | 0.3248E-01 | 0.2469E-01 |
| 0.4000E 04 | 0.4202E-01 | 0.5206E 03 | 0.5206E 03 | 0.3193E 01 | 0.5301E 03 | 0.3196E 01 | 0.2339E 01 |
| 0.6000E 04 | 0.2472E-01 | 0.1184E 04 | 0.1184E 04 | 0.1182E 03 | 0.1223E 04 | 0.1191E 03 | 0.1046E 03 |
| 0.8000E 04 | 0.1346E-01 | 0.2060E 04 | 0.2060E 04 | 0.8723E 03 | 0.2149E 04 | 0.8912E 03 | 0.1035E 04 |
| 0.1000E 05 | 0.9836E-02 | 0.3295E 04 | 0.3295E 04 | 0.2579E 04 | 0.3480E 04 | 0.2694E 04 | 0.2837E 04 |
| 0.1200E 05 | 0.7322E-02 | 0.4732E 04 | 0.4732E 04 | 0.4333E 04 | 0.5053E 04 | 0.4602E 04 | 0.4530E 04 |
| 0.1400E 05 | 0.5120E-02 | 0.6184E 04 | 0.6184E 04 | 0.5969E 04 | 0.6649E 04 | 0.6399E 04 | 0.6094E 04 |
| 0.1600E 05 | 0.3741E-02 | 0.7382E 04 | 0.7382E 04 | 0.7274E 04 | 0.7910E 04 | 0.7784E 04 | 0.7321E 04 |
| 0.1800E 05 | 0.3027E-02 | 0.8481E 04 | 0.8482E 04 | 0.8428E 04 | 0.9048E 04 | 0.8985E 04 | 0.8442E 04 |
| 0.2000E 05 | 0.2609E-02 | 0.9512E 04 | 0.9521E 04 | 0.9494E 04 | 0.1011E 05 | 0.1007E 05 | 0.9489E 04 |
| 0.2200E 05 | 0.2314E-02 | 0.1044E 05 | 0.1049E 05 | 0.1048E 05 | 0.1108E 05 | 0.1106E 05 | 0.1043E 05 |
| 0.2400E 05 | 0.2057E-02 | 0.1093E 05 | 0.1113E 05 | 0.1112E 05 | 0.1166E 05 | 0.1165E 05 | 0.1092E 05 |
| 0.2600E 05 | 0.1807E-02 | 0.1077E 05 | 0.1121E 05 | 0.1120E 05 | 0.1165E 05 | 0.1164E 05 | 0.1073E 05 |
| 0.2800E 05 | 0.1557E-02 | 0.1077E 05 | 0.1150E 05 | 0.1149E 05 | 0.1189E 05 | 0.1189E 05 | 0.1083E 05 |

(h) Pressure = 0.8 atm

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.3000E 04 | 0.6986E-01 | 0.2736E 03 | 0.2736E 03 | 0.2981E-01 | 0.2762E 03 | 0.2981E-01 | 0.2268E-01 |
| 0.4000E 04 | 0.4803E-01 | 0.5230E 03 | 0.5230E 03 | 0.3050E 01 | 0.5325E 03 | 0.3052E 01 | 0.2232E 01 |
| 0.6000E 04 | 0.2838E-01 | 0.1194E 04 | 0.1194E 04 | 0.1153E 03 | 0.1235E 04 | 0.1161E 03 | 0.1013E 03 |
| 0.8000E 04 | 0.1549E-01 | 0.2077E 04 | 0.2077E 04 | 0.8474E 03 | 0.2167E 04 | 0.8656E 03 | 0.1003E 04 |
| 0.1000E 05 | 0.1127E-01 | 0.3322E 04 | 0.3322E 04 | 0.2547E 04 | 0.3512E 04 | 0.2661E 04 | 0.2812E 04 |
| 0.1200E 05 | 0.8446E-02 | 0.4775E 04 | 0.4775E 04 | 0.4356E 04 | 0.5105E 04 | 0.4629E 04 | 0.4563E 04 |
| 0.1400E 05 | 0.5946E-02 | 0.6256E 04 | 0.6256E 04 | 0.6025E 04 | 0.6735E 04 | 0.6467E 04 | 0.6159E 04 |
| 0.1600E 05 | 0.4329E-02 | 0.7483E 04 | 0.7483E 04 | 0.7365E 04 | 0.8031E 04 | 0.7894E 04 | 0.7417E 04 |
| 0.1800E 05 | 0.3482E-02 | 0.8606E 04 | 0.8607E 04 | 0.8547E 04 | 0.9197E 04 | 0.9127E 04 | 0.8563E 04 |
| 0.2000E 05 | 0.2991E-02 | 0.9656E 04 | 0.9665E 04 | 0.9634E 04 | 0.1028E 05 | 0.1024E 05 | 0.9631E 04 |
| 0.2200E 05 | 0.2650E-02 | 0.1061E 05 | 0.1066E 05 | 0.1064E 05 | 0.1127E 05 | 0.1125E 05 | 0.1060E 05 |
| 0.2400E 05 | 0.2358E-02 | 0.1115E 05 | 0.1133E 05 | 0.1132E 05 | 0.1189E 05 | 0.1188E 05 | 0.1113E 05 |
| 0.2600E 05 | 0.2077E-02 | 0.1105E 05 | 0.1147E 05 | 0.1147E 05 | 0.1195E 05 | 0.1194E 05 | 0.1101E 05 |
| 0.2800E 05 | 0.1794E-02 | 0.1107E 05 | 0.1179E 05 | 0.1178E 05 | 0.1222E 05 | 0.1221E 05 | 0.1113E 05 |

[a]See footnote, page 19.

TABLE 6.– ELECTRICAL CONDUCTIVITY OF EQUILIBRIUM AIR AT NUMEROUS PRESSURES AND TEMPERATURES CALCULATED ACCORDING TO METHODS DESCRIBED IN THE TEXT – Continued

(i) Pressure = 0.9 atm

| Temperature, °K | Density ratio | [a]Electrical conductivity, mhos/m | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| 0.3000E 04 | 0.7859E-01 | 0.2744E 03 | 0.2744E 03 | 0.2745E-01 | 0.2770E 03 | 0.2745E-01 | 0.2090E-01 |
| 0.4000E 04 | 0.5403E-01 | 0.5250E 03 | 0.5250E 03 | 0.2924E 01 | 0.5346E 03 | 0.2926E 01 | 0.2137E 01 |
| 0.6000E 04 | 0.3205E-01 | 0.1203E 04 | 0.1203E 04 | 0.1127E 03 | 0.1244E 04 | 0.1135E 03 | 0.9846E 02 |
| 0.8000E 04 | 0.1753E-01 | 0.2091E 04 | 0.2091E 04 | 0.8254E 03 | 0.2184E 04 | 0.8431E 03 | 0.9746E 03 |
| 0.1000E 05 | 0.1272E-01 | 0.3347E 04 | 0.3347E 04 | 0.2517E 04 | 0.3542E 04 | 0.2629E 04 | 0.2787E 04 |
| 0.1200E 05 | 0.9579E-02 | 0.4813E 04 | 0.4813E 04 | 0.4375E 04 | 0.5150E 04 | 0.4654E 04 | 0.4593E 04 |
| 0.1400E 05 | 0.6784E-02 | 0.6319E 04 | 0.6319E 04 | 0.6074E 04 | 0.6811E 04 | 0.6527E 04 | 0.6216E 04 |
| 0.1600E 05 | 0.4923E-02 | 0.7572E 04 | 0.7572E 04 | 0.7445E 04 | 0.8138E 04 | 0.7991E 04 | 0.7501E 04 |
| 0.1800E 05 | 0.3940E-02 | 0.8715E 04 | 0.8716E 04 | 0.8652E 04 | 0.9328E 04 | 0.9253E 04 | 0.8670E 04 |
| 0.2000E 05 | 0.3374E-02 | 0.9783E 04 | 0.9791E 04 | 0.9758E 04 | 0.1043E 05 | 0.1039E 05 | 0.9757E 04 |
| 0.2200E 05 | 0.2986E-02 | 0.1076E 05 | 0.1080E 05 | 0.1078E 05 | 0.1144E 05 | 0.1142E 05 | 0.1074E 05 |
| 0.2400E 05 | 0.2659E-02 | 0.1134E 05 | 0.1151E 05 | 0.1150E 05 | 0.1210E 05 | 0.1209E 05 | 0.1132E 05 |
| 0.2600E 05 | 0.2349E-02 | 0.1131E 05 | 0.1171E 05 | 0.1170E 05 | 0.1222E 05 | 0.1221E 05 | 0.1127E 05 |
| 0.2800E 05 | 0.2033E-02 | 0.1135E 05 | 0.1204E 05 | 0.1203E 05 | 0.1250E 05 | 0.1249E 05 | 0.1140E 05 |

(j) Pressure = 1.0 atm

| Temperature, °K | Density ratio | A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|
| 0.3000E 04 | 0.8732E-01 | 0.2752E 03 | 0.2752E 03 | 0.2534E-01 | 0.2777E 03 | 0.2534E-01 | 0.1931E-01 |
| 0.4000E 04 | 0.6003E-01 | 0.5268E 03 | 0.5268E 03 | 0.2810E 01 | 0.5365E 03 | 0.2812E 01 | 0.2052E 01 |
| 0.6000E 04 | 0.3574E-01 | 0.1211E 04 | 0.1211E 04 | 0.1104E 03 | 0.1253E 04 | 0.1112E 03 | 0.9589E 02 |
| 0.8000E 04 | 0.1958E-01 | 0.2104E 04 | 0.2104E 04 | 0.8058E 03 | 0.2199E 04 | 0.8230E 03 | 0.9495E 03 |
| 0.1000E 05 | 0.1416E-01 | 0.3369E 04 | 0.3369E 04 | 0.2490E 04 | 0.3568E 04 | 0.2601E 04 | 0.2764E 04 |
| 0.1200E 05 | 0.1070E-01 | 0.4848E 04 | 0.4848E 04 | 0.4373E 04 | 0.5193E 04 | 0.4653E 04 | 0.4604E 04 |
| 0.1400E 05 | 0.7633E-02 | 0.6375E 04 | 0.6375E 04 | 0.6118E 04 | 0.6879E 04 | 0.6581E 04 | 0.6267E 04 |
| 0.1600E 05 | 0.5524E-02 | 0.7651E 04 | 0.7651E 04 | 0.7517E 04 | 0.8234E 04 | 0.8077E 04 | 0.7576E 04 |
| 0.1800E 05 | 0.4401E-02 | 0.8814E 04 | 0.8814E 04 | 0.8745E 04 | 0.9445E 04 | 0.9365E 04 | 0.8766E 04 |
| 0.2000E 05 | 0.3758E-02 | 0.9897E 04 | 0.9905E 04 | 0.9869E 04 | 0.1056E 05 | 0.1052E 05 | 0.9870E 04 |
| 0.2200E 05 | 0.3323E-02 | 0.1089E 05 | 0.1093E 05 | 0.1091E 05 | 0.1159E 05 | 0.1157E 05 | 0.1088E 05 |
| 0.2400E 05 | 0.2961E-02 | 0.1151E 05 | 0.1167E 05 | 0.1166E 05 | 0.1229E 05 | 0.1228E 05 | 0.1149E 05 |
| 0.2600E 05 | 0.2621E-02 | 0.1153E 05 | 0.1192E 05 | 0.1191E 05 | 0.1246E 05 | 0.1245E 05 | 0.1149E 05 |
| 0.2800E 05 | 0.2274E-02 | 0.1159E 05 | 0.1227E 05 | 0.1226E 05 | 0.1276E 05 | 0.1275E 05 | 0.1163E 05 |

[a]See footnote, page 19.

TABLE 6.– ELECTRICAL CONDUCTIVITY OF EQUILIBRIUM AIR AT NUMEROUS PRESSURES AND TEMPERATURES CALCULATED ACCORDING TO METHODS DESCRIBED IN THE TEXT – Continued

(k) Pressure = 3.0 atm

| Temperature, °K | Density ratio | [a]Electrical conductivity, mhos/m | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| 0.3000E 04 | 0.2620E 00 | 0.2740E 03 | 0.2740E 03 | 0.1613E-01 | 0.2762E 03 | 0.1613E-01 | 0.1230E-01 |
| 0.4000E 04 | 0.1821E 00 | 0.5341E 03 | 0.5341E 03 | 0.1891E 01 | 0.5438E 03 | 0.1892E 01 | 0.1372E 01 |
| 0.6000E 04 | 0.1112E 00 | 0.1294E 04 | 0.1294E 04 | 0.8693E 02 | 0.1344E 04 | 0.8750E 02 | 0.7006E 02 |
| 0.8000E 04 | 0.6212E-01 | 0.2239E 04 | 0.2239E 04 | 0.6011E 03 | 0.2353E 04 | 0.6129E 03 | 0.6874E 03 |
| 0.1000E 05 | 0.4354E-01 | 0.3599E 04 | 0.3599E 04 | 0.2208E 04 | 0.3843E 04 | 0.2304E 04 | 0.2529E 04 |
| 0.1200E 05 | 0.3363E-01 | 0.5215E 04 | 0.5215E 04 | 0.4224E 04 | 0.5650E 04 | 0.4506E 04 | 0.4618E 04 |
| 0.1400E 05 | 0.2529E-01 | 0.7017E 04 | 0.7017E 04 | 0.6357E 04 | 0.7708E 04 | 0.6912E 04 | 0.6668E 04 |
| 0.1600E 05 | 0.1857E-01 | 0.8554E 04 | 0.8554E 04 | 0.8168E 04 | 0.9384E 04 | 0.8912E 04 | 0.8336E 04 |
| 0.1800E 05 | 0.1420E-01 | 0.9938E 04 | 0.9938E 04 | 0.9734E 04 | 0.1085E 05 | 0.1060E 05 | 0.9819E 04 |
| 0.2000E 05 | 0.1167E-01 | 0.1116E 05 | 0.1116E 05 | 0.1107E 05 | 0.1209E 05 | 0.1197E 05 | 0.1110E 05 |
| 0.2200E 05 | 0.1014E-01 | 0.1228E 05 | 0.1229E 05 | 0.1225E 05 | 0.1320E 05 | 0.1316E 05 | 0.1225E 05 |
| 0.2400E 05 | 0.9101E-02 | 0.1328E 05 | 0.1335E 05 | 0.1333E 05 | 0.1425E 05 | 0.1422E 05 | 0.1325E 05 |
| 0.2600E 05 | 0.8246E-02 | 0.1389E 05 | 0.1412E 05 | 0.1410E 05 | 0.1495E 05 | 0.1494E 05 | 0.1383E 05 |
| 0.2800E 05 | 0.7304E-02 | 0.1413E 05 | 0.1466E 05 | 0.1464E 05 | 0.1542E 05 | 0.1541E 05 | 0.1411E 05 |

(l) Pressure = 10.0 atm

| Temperature, °K | Density ratio | A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|
| 0.3000E 04 | 0.8732E 00 | 0.2714E 03 | 0.2714E 03 | 0.8000E-02 | 0.2731E 03 | 0.8000E-02 | 0.6112E-02 |
| 0.4000E 04 | 0.6209E 00 | 0.5310E 03 | 0.5310E 03 | 0.1131E 01 | 0.5401E 03 | 0.1132E 01 | 0.8196E 00 |
| 0.6000E 04 | 0.3872E 00 | 0.1378E 04 | 0.1378E 04 | 0.6671E 02 | 0.1437E 04 | 0.6710E 02 | 0.5190E 02 |
| 0.8000E 04 | 0.2271E 00 | 0.2438E 04 | 0.2438E 04 | 0.4402E 03 | 0.2585E 04 | 0.4481E 03 | 0.4760E 03 |
| 0.1000E 05 | 0.1506E 00 | 0.3880E 04 | 0.3880E 04 | 0.1847E 04 | 0.4188E 04 | 0.1925E 04 | 0.2168E 04 |
| 0.1200E 05 | 0.1178E 00 | 0.5636E 04 | 0.5636E 04 | 0.4008E 04 | 0.6183E 04 | 0.4288E 04 | 0.4567E 04 |
| 0.1400E 05 | 0.9305E-01 | 0.7738E 04 | 0.7738E 04 | 0.6551E 04 | 0.8653E 04 | 0.7205E 04 | 0.7066E 04 |
| 0.1600E 05 | 0.7098E-01 | 0.9624E 04 | 0.9624E 04 | 0.8779E 04 | 0.1081E 05 | 0.9756E 04 | 0.9141E 04 |
| 0.1800E 05 | 0.5385E-01 | 0.1144E 05 | 0.1144E 05 | 0.1085E 05 | 0.1288E 05 | 0.1213E 05 | 0.1112E 05 |
| 0.2000E 05 | 0.4338E-01 | 0.1308E 05 | 0.1308E 05 | 0.1269E 05 | 0.1467E 05 | 0.1416E 05 | 0.1287E 05 |
| 0.2200E 05 | 0.3635E-01 | 0.1450E 05 | 0.1451E 05 | 0.1425E 05 | 0.1614E 05 | 0.1581E 05 | 0.1435E 05 |
| 0.2400E 05 | 0.3185E-01 | 0.1582E 05 | 0.1585E 05 | 0.1568E 05 | 0.1749E 05 | 0.1728E 05 | 0.1570E 05 |
| 0.2600E 05 | 0.2853E-01 | 0.1686E 05 | 0.1699E 05 | 0.1687E 05 | 0.1858E 05 | 0.1843E 05 | 0.1675E 05 |
| 0.2800E 05 | 0.2557E-01 | 0.1765E 05 | 0.1799E 05 | 0.1790E 05 | 0.1954E 05 | 0.1944E 05 | 0.1761E 05 |

[a]See footnote, page 19.

TABLE 6.– ELECTRICAL CONDUCTIVITY OF EQUILIBRIUM AIR AT NUMEROUS PRESSURES AND TEMPERATURES CALCULATED ACCORDING TO METHODS DESCRIBED IN THE TEXT – Concluded

(m) Pressure = 30.0 atm

| Temperature, °K | Density ratio | [a]Electrical conductivity, mhos/m | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| 0.3000E 04 | 0.2731E 01 | 0.2570E 03 | 0.2570E 03 | 0.4908E-02 | 0.2587E 03 | 0.4908E-02 | 0.3752E-02 |
| 0.4000E 04 | 0.1929E 01 | 0.5009E 03 | 0.5009E 03 | 0.6694E 00 | 0.5093E 03 | 0.6695E 00 | 0.4845E 00 |
| 0.6000E 04 | 0.1205E 01 | 0.1428E 04 | 0.1428E 04 | 0.4901E 02 | 0.1493E 04 | 0.4926E 02 | 0.3631E 02 |
| 0.8000E 04 | 0.7537E 00 | 0.2646E 04 | 0.2646E 04 | 0.3283E 03 | 0.2831E 04 | 0.3339E 03 | 0.3247E 03 |
| 0.1000E 05 | 0.4771E 00 | 0.4194E 04 | 0.4194E 04 | 0.1420E 04 | 0.4583E 04 | 0.1476E 04 | 0.1645E 04 |
| 0.1200E 05 | 0.3668E 00 | 0.6138E 04 | 0.6138E 04 | 0.3496E 04 | 0.6870E 04 | 0.3740E 04 | 0.4123E 04 |
| 0.1400E 05 | 0.2900E 00 | 0.8452E 04 | 0.8452E 04 | 0.6142E 04 | 0.9717E 04 | 0.6791E 04 | 0.6822E 04 |
| 0.1600E 05 | 0.2313E 00 | 0.1076E 05 | 0.1076E 05 | 0.8853E 04 | 0.1259E 05 | 0.1002E 05 | 0.9502E 04 |
| 0.1800E 05 | 0.1804E 00 | 0.1301E 05 | 0.1301E 05 | 0.1154E 05 | 0.1534E 05 | 0.1326E 05 | 0.1211E 05 |
| 0.2000E 05 | 0.1448E 00 | 0.1501E 05 | 0.1501E 05 | 0.1399E 05 | 0.1760E 05 | 0.1613E 05 | 0.1441E 05 |
| 0.2200E 05 | 0.1174E 00 | 0.1667E 05 | 0.1667E 05 | 0.1606E 05 | 0.1922E 05 | 0.1835E 05 | 0.1630E 05 |
| 0.2400E 05 | 0.1001E 00 | 0.1817E 05 | 0.1819E 05 | 0.1787E 05 | 0.2054E 05 | 0.2013E 05 | 0.1797E 05 |
| 0.2600E 05 | 0.8836E-01 | 0.1963E 05 | 0.1968E 05 | 0.1945E 05 | 0.2204E 05 | 0.2175E 05 | 0.1947E 05 |
| 0.2800E 05 | 0.7960E-01 | 0.2107E 05 | 0.2124E 05 | 0.2107E 05 | 0.2366E 05 | 0.2345E 05 | 0.2103E 05 |

[a]See footnote, page 19.

TABLE 7.– VALUES OF COULOMBIC COLLISION FREQUENCY PARAMETERS FOR EQUILIBRIUM AIR AT VARIOUS TEMPERATURES AND DENSITIES

(a) $\Gamma_{ee}$, cm$^6$/sec$^4$

| Temp., °K | Density ratios ($\rho/\rho_0$ where $\rho_0 = 1.225 \times 10^{-3}$ g/cm$^3$) 10-6 | 10-5 | 10-4 | 10-3 | 10-2 | 10-1 | 10+0 | 10+1 | 10+2 |
|---|---|---|---|---|---|---|---|---|---|
| 3000 | 1.0260E 19 | 9.5661E 18 | 8.8850E 18 | 8.2587E 18 | 7.7210E 18 | 7.2344E 18 | 6.7726E 18 | 6.3347E 18 | 5.9403E 18 |
| 4000 | 9.0518E 18 | 8.3403E 18 | 7.6404E 18 | 6.9468E 18 | 6.2673E 18 | 5.6430E 18 | 5.1146E 18 | 4.6688E 18 | 4.2972E 18 |
| 6000 | 7.3507E 18 | 6.8830E 18 | 6.3945E 18 | 5.8094E 18 | 5.1236E 18 | 4.4280E 18 | 3.7606E 18 | 3.1829E 18 | 2.7633E 18 |
| 8000 | 6.2808E 18 | 5.7742E 18 | 5.2965E 18 | 4.8276E 18 | 4.3557E 18 | 3.8355E 18 | 3.2079E 18 | 2.5707E 18 | 2.0623E 18 |
| 10000 | 6.0581E 18 | 5.2956E 18 | 4.7195E 18 | 4.2153E 18 | 3.7385E 18 | 3.2681E 18 | 2.7782E 18 | 2.2125E 18 | 1.6665E 18 |
| 12000 | 6.2385E 18 | 5.3358E 18 | 4.5439E 18 | 3.9013E 18 | 3.3666E 18 | 2.9026E 18 | 2.4289E 18 | 1.9350E 18 | 1.4290E 18 |
| 14000 | 6.4228E 18 | 5.4949E 18 | 4.5942E 18 | 3.7902E 18 | 3.1723E 18 | 2.6592E 18 | 2.1795E 18 | 1.7053E 18 | 1.2201E 18 |
| 16000 | 6.5703E 18 | 5.6522E 18 | 4.7283E 18 | 3.8501E 18 | 3.0962E 18 | 2.5204E 18 | 2.0157E 18 | 1.5408E 18 | 1.0660E 18 |
| 18000 | 6.6192E 18 | 5.7750E 18 | 4.8686E 18 | 3.9593E 18 | 3.1160E 18 | 2.4553E 18 | 1.9161E 18 | 1.4300E 18 | 9.6526E 17 |
| 20000 | 6.6482E 18 | 5.8369E 18 | 4.9861E 18 | 4.0742E 18 | 3.1884E 18 | 2.4386E 18 | 1.8615E 18 | 1.3499E 18 | 8.8915E 17 |
| 22000 | 6.7168E 18 | 5.8542E 18 | 5.0512E 18 | 4.1773E 18 | 3.2721E 18 | 2.4657E 18 | 1.8268E 18 | 1.3025E 18 | 8.3350E 17 |
| 24000 | 6.7963E 18 | 5.9112E 18 | 5.0832E 18 | 4.2555E 18 | 3.3687E 18 | 2.5132E 18 | 1.8243E 18 | 1.2770E 18 | 8.0107E 17 |
| 26000 | 6.8859E 18 | 5.9753E 18 | 5.1119E 18 | 4.3098E 18 | 3.4529E 18 | 2.5768E 18 | 1.8438E 18 | 1.2636E 18 | 7.7397E 17 |
| 28000 | 6.9597E 18 | 6.0597E 18 | 5.1662E 18 | 4.3231E 18 | 3.5210E 18 | 2.6384E 18 | 1.8656E 18 | 1.2639E 18 | 7.6090E 17 |

(b) $\Gamma_{eI}$, cm$^6$/sec$^4$

| Temp., °K | 10-6 | 10-5 | 10-4 | 10-3 | 10-2 | 10-1 | 10+0 | 10+1 | 10+2 |
|---|---|---|---|---|---|---|---|---|---|
| 3000 | 1.0271E 19 | 9.5708E 18 | 8.8850E 18 | 8.2682E 18 | 7.8183E 18 | 7.3926E 18 | 7.7888E 18 | 9.3734E 18 | 1.4979E 19 |
| 4000 | 9.0488E 18 | 8.3369E 18 | 7.6424E 18 | 6.9561E 18 | 6.3049E 18 | 5.9125E 18 | 6.2222E 18 | 8.3634E 18 | 1.5533E 19 |
| 6000 | 7.3423E 18 | 6.8928E 18 | 6.3930E 18 | 5.8097E 18 | 5.1281E 18 | 4.4687E 18 | 4.0763E 18 | 5.0301E 18 | 1.0359E 19 |
| 8000 | 6.2804E 18 | 5.7743E 18 | 5.2964E 18 | 4.8278E 18 | 4.3570E 18 | 3.8491E 18 | 3.3064E 18 | 3.2539E 18 | 5.6755E 18 |
| 10000 | 6.0572E 18 | 5.2952E 18 | 4.7189E 18 | 4.2153E 18 | 3.7403E 18 | 3.2733E 18 | 2.8203E 18 | 2.5224E 18 | 3.4859E 18 |
| 12000 | 6.2518E 18 | 5.3174E 18 | 4.6178E 18 | 3.9439E 18 | 3.3541E 18 | 2.9189E 18 | 2.4803E 18 | 2.1140E 18 | 2.3969E 18 |
| 14000 | 6.4460E 18 | 5.4379E 18 | 4.5639E 18 | 3.7735E 18 | 3.1233E 18 | 2.6079E 18 | 2.2281E 18 | 1.8211E 18 | 1.7846E 18 |
| 16000 | 7.0062E 18 | 5.6705E 18 | 4.6974E 18 | 3.8572E 18 | 3.0965E 18 | 2.5217E 18 | 2.0460E 18 | 1.6058E 18 | 1.4328E 18 |
| 18000 | 9.1011E 18 | 6.1276E 18 | 4.9021E 18 | 3.9763E 18 | 3.1231E 18 | 2.4505E 18 | 1.9227E 18 | 1.4704E 18 | 1.2404E 18 |
| 20000 | 1.1022E 19 | 7.5929E 18 | 5.3104E 18 | 4.1082E 18 | 3.1910E 18 | 2.4373E 18 | 1.8681E 18 | 1.3735E 18 | 1.0951E 18 |
| 22000 | 1.2031E 19 | 9.2992E 18 | 6.1716E 18 | 4.2816E 18 | 3.2838E 18 | 2.4765E 18 | 1.8248E 18 | 1.3297E 18 | 9.8466E 17 |
| 24000 | 1.2360E 19 | 1.0257E 19 | 7.2627E 18 | 4.7037E 18 | 3.4137E 18 | 2.5250E 18 | 1.8273E 18 | 1.3025E 18 | 9.2989E 17 |
| 26000 | 1.2857E 19 | 1.0656E 19 | 8.1535E 18 | 5.4816E 18 | 3.6244E 18 | 2.5939E 18 | 1.8488E 18 | 1.2783E 18 | 8.7261E 17 |
| 28000 | 1.3392E 19 | 1.1091E 19 | 8.8102E 18 | 5.9258E 18 | 3.8947E 18 | 2.6395E 18 | 1.8754E 18 | 1.2730E 18 | 8.2915E 17 |

TABLE 8.– VALUES OF $\sigma_{SHU}(2)$ (mhos/m) FOR EQUILIBRIUM AIR AT VARIOUS TEMPERATURES AND DENSITIES

| Temp., °K | Density ratios ($\rho/\rho_o$ where $\rho_o$ = 1.225X10$^{-3}$ g/cm$^3$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10-6 | 10-5 | 10-4 | 10-3 | 10-2 | 10-1 | 10+0 | 10+1 | 10+2 |
| 3000 | 1.9744E 02 | 2.1224E 02 | 2.2908E 02 | 2.4680E 02 | 2.6233E 02 | 2.7871E 02 | 2.7272E 02 | 2.4051E 02 | 1.6779E 02 |
| 4000 | 3.4608E 02 | 3.7657E 02 | 4.1209E 02 | 4.5453E 02 | 5.0429E 02 | 5.4564E 02 | 5.3864E 02 | 4.3563E 02 | 2.6415E 02 |
| 6000 | 7.8888E 02 | 8.4305E 02 | 9.1153E 02 | 1.0079E 03 | 1.1504E 03 | 1.3362E 03 | 1.5075E 03 | 1.3278E 03 | 7.3304E 02 |
| 8000 | 1.4298E 03 | 1.5617E 03 | 1.7109E 03 | 1.8883E 03 | 2.1088E 03 | 2.4166E 03 | 2.8887E 03 | 3.1448E 03 | 2.0506E 03 |
| 10000 | 2.0754E 03 | 2.3916E 03 | 2.7041E 03 | 3.0545E 03 | 3.4829E 03 | 4.0470E 03 | 4.8375E 03 | 5.8345E 03 | 5.2994E 03 |
| 12000 | 2.6409E 03 | 3.1270E 03 | 3.6554E 03 | 4.3319E 03 | 5.1659E 03 | 6.0842E 03 | 7.4759E 03 | 9.7506E 03 | 7.6664E 03 |
| 14000 | 3.2245E 03 | 3.8405E 03 | 4.6344E 03 | 5.7050E 03 | 7.0356E 03 | 8.7049E 03 | 1.0893E 04 | 1.6169E 04 | 1.2611E 04 |
| 16000 | 3.6740E 03 | 4.5067E 03 | 5.4896E 03 | 6.8160E 03 | 8.7257E 03 | 1.1176E 04 | 1.5054E 04 | 2.8617E 04 | 1.8839E 04 |
| 18000 | 3.5800E 03 | 5.0373E 03 | 6.2830E 03 | 7.8718E 03 | 1.0317E 04 | 1.3819E 04 | 1.9748E 04 | 6.6179E 04 | 2.5702E 04 |
| 20000 | 3.6076E 03 | 4.9863E 03 | 6.8697E 03 | 8.9083E 03 | 1.1783E 04 | 1.6308E 04 | 2.4359E 04 | 2.5541E 04 | 3.3758E 04 |
| 22000 | 3.8752E 03 | 4.9050E 03 | 7.0284E 03 | 9.8778E 03 | 1.3169E 04 | 1.8470E 04 | 2.9263E 04 | 3.0471E 04 | 4.2874E 04 |
| 24000 | 4.3106E 03 | 5.1599E 03 | 7.0370E 03 | 1.0402E 04 | 1.4410E 04 | 2.0538E 04 | 3.3351E 04 | 3.5435E 04 | 5.1500E 04 |
| 26000 | 4.6971E 03 | 5.6301E 03 | 7.2289E 03 | 1.0360E 04 | 1.5372E 04 | 2.2415E 04 | 3.6816E 04 | 4.0601E 04 | 6.1411E 04 |
| 28000 | 5.0702E 03 | 6.0753E 03 | 7.5748E 03 | 1.0881E 04 | 1.6140E 04 | 2.4485E 04 | 4.0185E 04 | 4.5496E 04 | 7.1559E 04 |

TABLE 9.– APPROXIMATE VALUES OF THE COLLISION FREQUENCY RATIO $\nu_N/\nu_{ei}$ FOR EQUILIBRIUM AIR AT VARIOUS TEMPERATURES AND DENSITIES

| Temp., °K | Density ratios ($\rho/\rho_o$ where $\rho_o$ = 1.225X10$^{-3}$ g/cm$^3$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10-6 | 10-5 | 10-4 | 10-3 | 10-2 | 10-1 | 10+0 | 10+1 | 10+2 |
| 3000 | 1.0118E 02 | 1.9428E 02 | 3.8725E 02 | 8.9233E 02 | 2.5518E 03 | 8.2144E 03 | 2.7963E 04 | 1.0095E 05 | 4.0497E 05 |
| 4000 | 4.7855E 00 | 9.0800E 00 | 1.7581E 01 | 3.4701E 01 | 7.1586E 01 | 1.6993E 02 | 5.0952E 02 | 1.8548E 03 | 8.0225E 03 |
| 6000 | 5.2937E-02 | 1.7883E-01 | 5.9332E-01 | 1.7202E 00 | 3.9878E 00 | 8.6356E 00 | 1.9704E 01 | 5.5520E 01 | 2.2490E 02 |
| 8000 | 2.4734E-03 | 9.4510E-03 | 3.3701E-02 | 1.1844E-01 | 4.2382E-01 | 1.5013E 00 | 4.2938E 00 | 1.1603E 01 | 4.1205E 01 |
| 10000 | 1.6628E-04 | 1.1976E-03 | 5.6811E-03 | 2.2161E-02 | 8.1721E-02 | 3.0396E-01 | 1.2013E 00 | 4.3574E 00 | 1.5978E 01 |
| 12000 | 1.1008E-05 | 1.3796E-04 | 1.1465E-03 | 6.0622E-03 | 2.4869E-02 | 1.0099E-01 | 3.8802E-01 | 1.6830E 00 | 7.5773E 00 |
| 14000 | 2.0508E-06 | 2.2333E-05 | 2.5141E-04 | 2.1190E-03 | 1.1901E-02 | 5.1780E-02 | 2.1055E-01 | 8.9840E-01 | 4.3499E 00 |
| 16000 | 4.7181E-07 | 5.8517E-06 | 6.6682E-05 | 7.4263E-04 | 5.6929E-03 | 2.9422E-02 | 1.2694E-01 | 5.4929E-01 | 2.7111E 00 |
| 18000 | 0.0 | 1.8735E-06 | 2.2367E-05 | 2.8116E-04 | 2.7639E-03 | 1.8072E-02 | 8.6592E-02 | 3.8546E-01 | 1.9850E 00 |
| 20000 | 0.0 | 3.9503E-07 | 9.4586E-06 | 1.1861E-04 | 1.3544E-03 | 1.1228E-02 | 6.2487E-02 | 2.9325E-01 | 1.5393E 00 |
| 22000 | 0.0 | 0.0 | 4.1678E-06 | 5.7851E-05 | 7.1280E-04 | 7.1568E-03 | 4.6115E-02 | 2.3766E-01 | 1.2561E 00 |
| 24000 | 0.0 | 0.0 | 1.7348E-06 | 3.1137E-05 | 4.1066E-04 | 4.6579E-03 | 3.5182E-02 | 1.9465E-01 | 1.0709E 00 |
| 26000 | 0.0 | 0.0 | 0.0 | 1.7429E-05 | 2.5997E-04 | 3.1705E-03 | 2.7534E-02 | 1.6321E-01 | 9.4024E-01 |
| 28000 | 0.0 | 0.0 | 0.0 | 8.7296E-06 | 1.6456E-04 | 2.1664E-03 | 2.1565E-02 | 1.4267E-01 | 8.3356E-01 |

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